Recent Heavy Flavor Results from CMS

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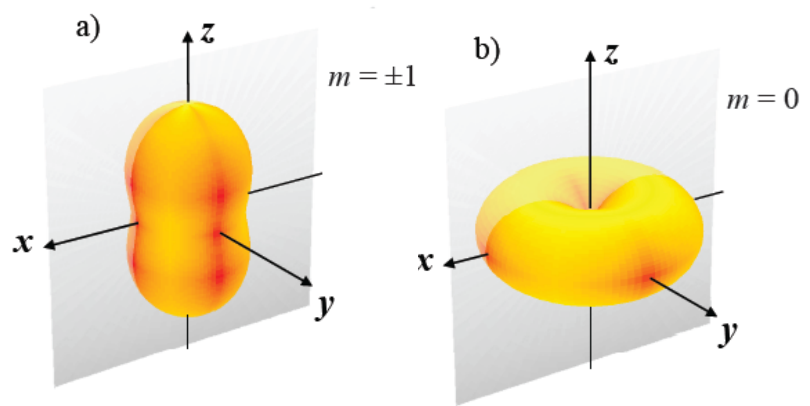
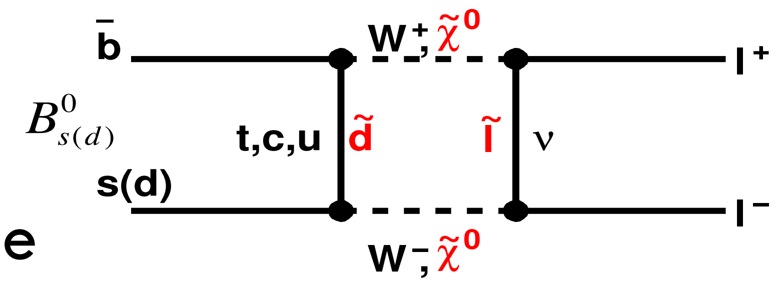
Why flavor physics?

- Study of B hadron production and properties
  - Masses, lifetimes, branching ratios…
- Quarkonium production properties
  - Polarization, production ratios…



- Search for and study new or exotic states
  - Quarkonia-like states: X, Y, Z's
  - New b-baryons
- Indirect searches for new physics
  - New heavy particles in loops can induce measurable non-SM effects
  - Complementary to the direct search program



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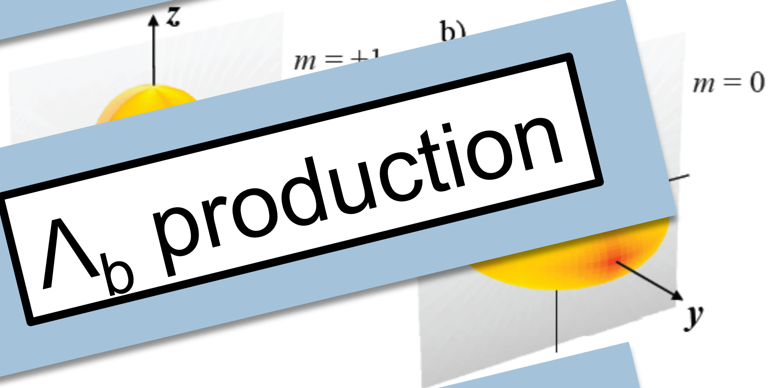
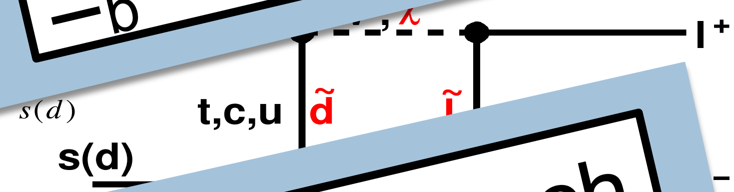
This talk



Λ_b production

Ξ_b^* discovery

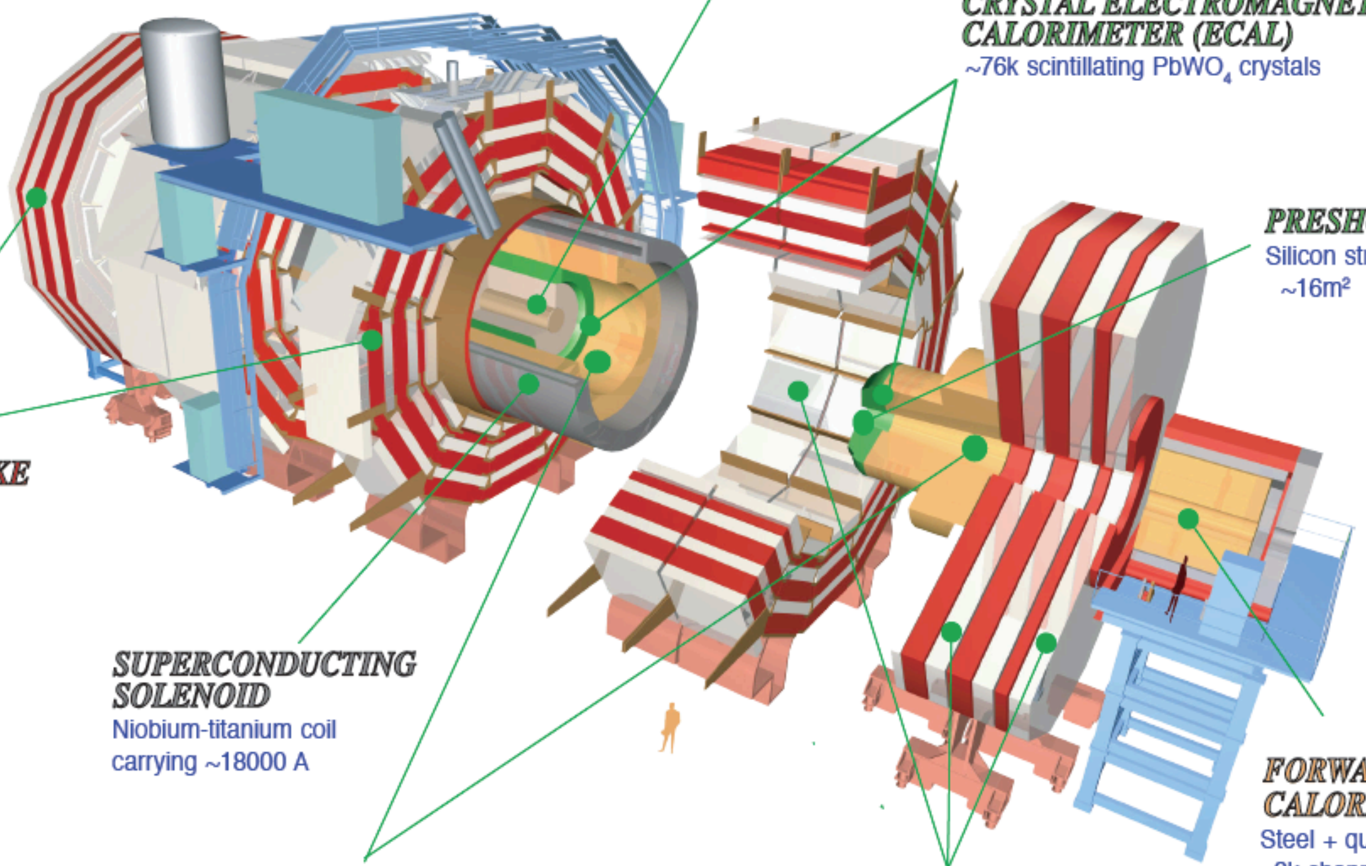


$B_s \to \mu^+\mu^-$ search

The CMS detector

JINST 3, S08004 (2008)

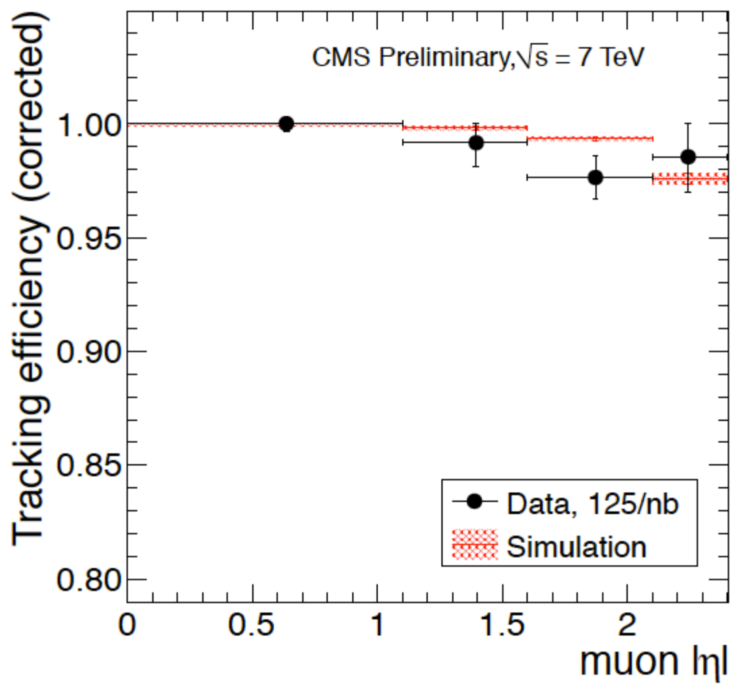
Pixels
Tracker
ECAL
HCAL
Solenoid
Steel Yoke
Muons

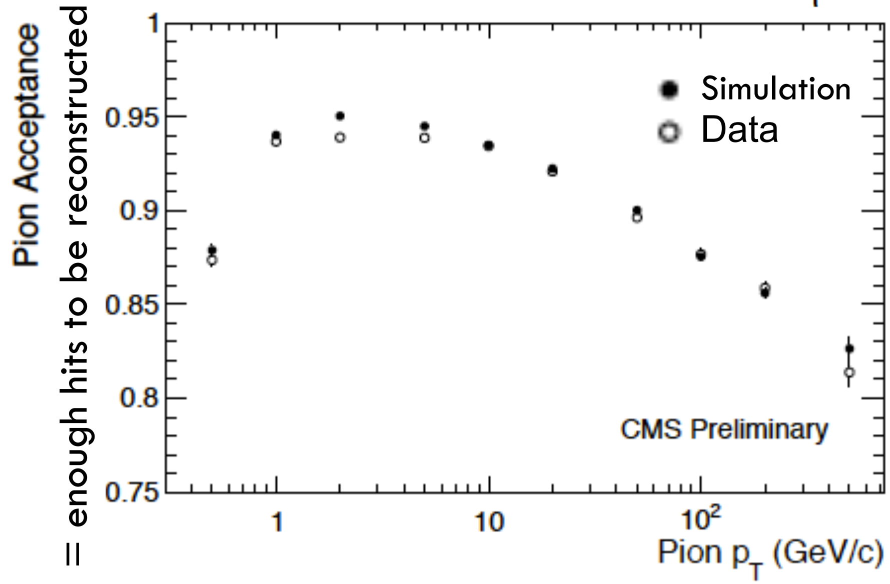


Total weight	**: 14000 tonnes**
Overall diameter	**: 15.0 m**
Overall length	**: 28.7 m**
Magnetic field	**: 3.8 T**

Tracking efficiency

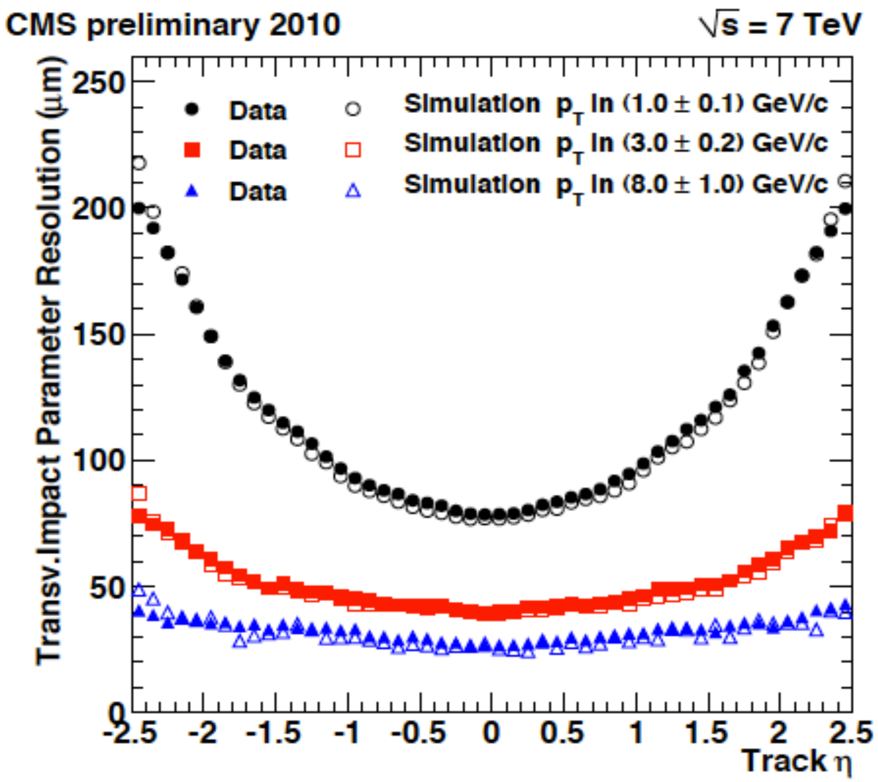
- Silicon tracker covers out to $|\eta|<2.4$ and down to track $p_T > 300$ MeV
- Great track reconstruction efficiency
  - Measured in data with good agreement with simulation
  - ~100% for central muons
  - Hadron efficiency 85-95% due to tracks lost in interactions
  - Excellent displaced track reconstruction out to 50 cm displacement from beamline

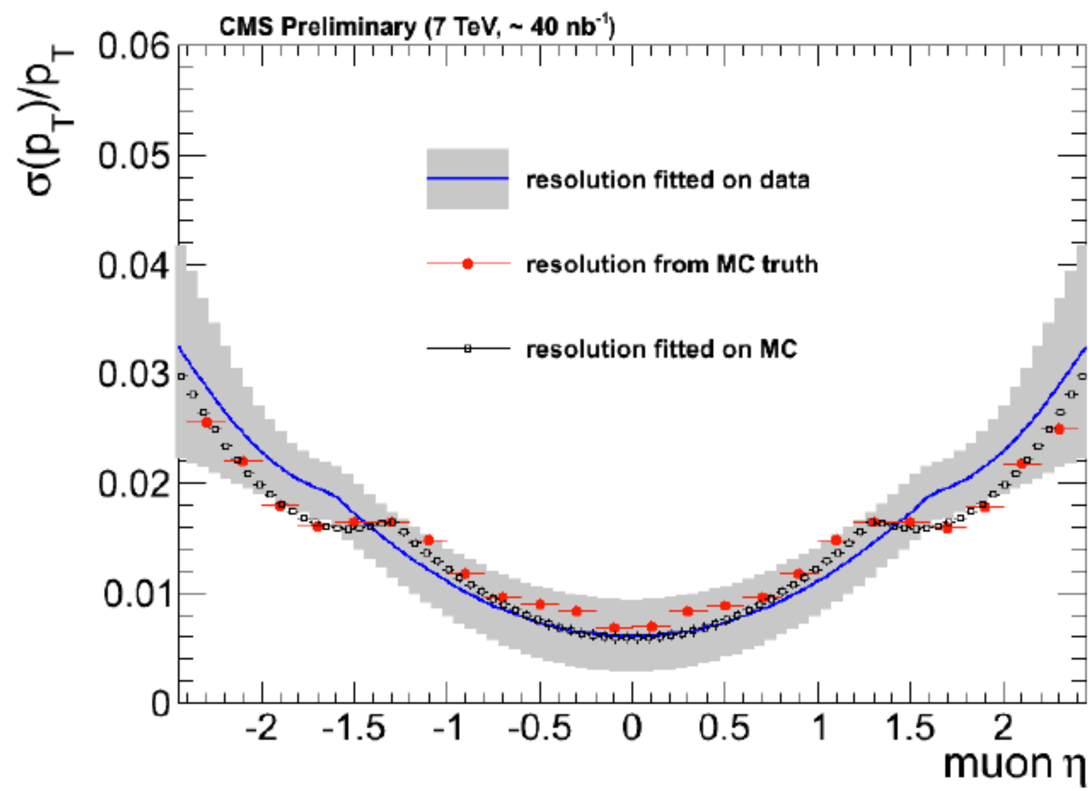




Tracking performance

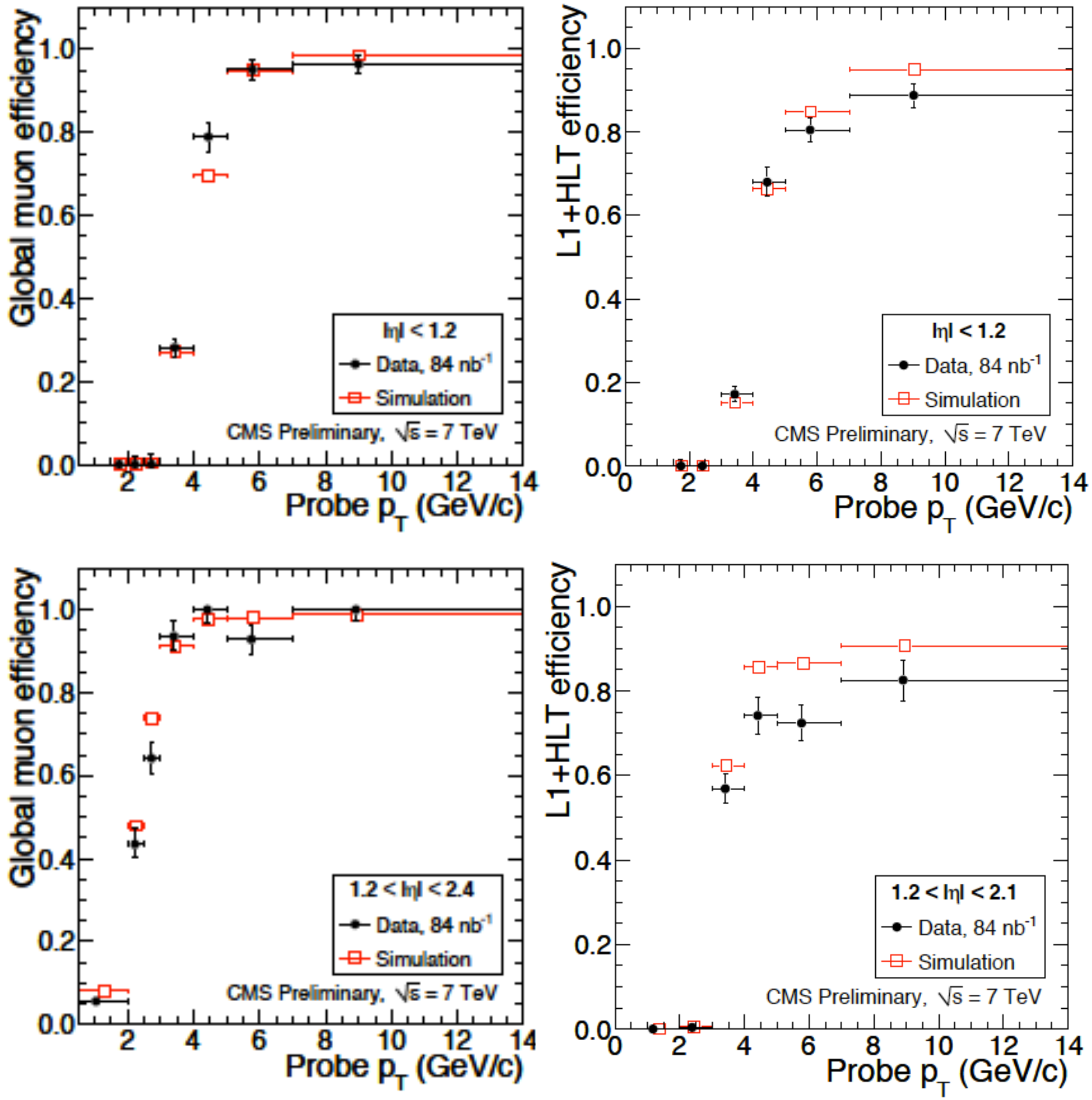
- Track impact parameter resolution 25-200 μm
  - Improves with higher p_T and smaller η
- Track momentum resolution 0.6-3.0%
  - Improves with smaller η
- Provides good mass and lifetime resolution
  - For $B^+ \rightarrow J/\psi K^+$ decays mass resolution ~30 MeV and core $c\tau$ resolution ~30 μm



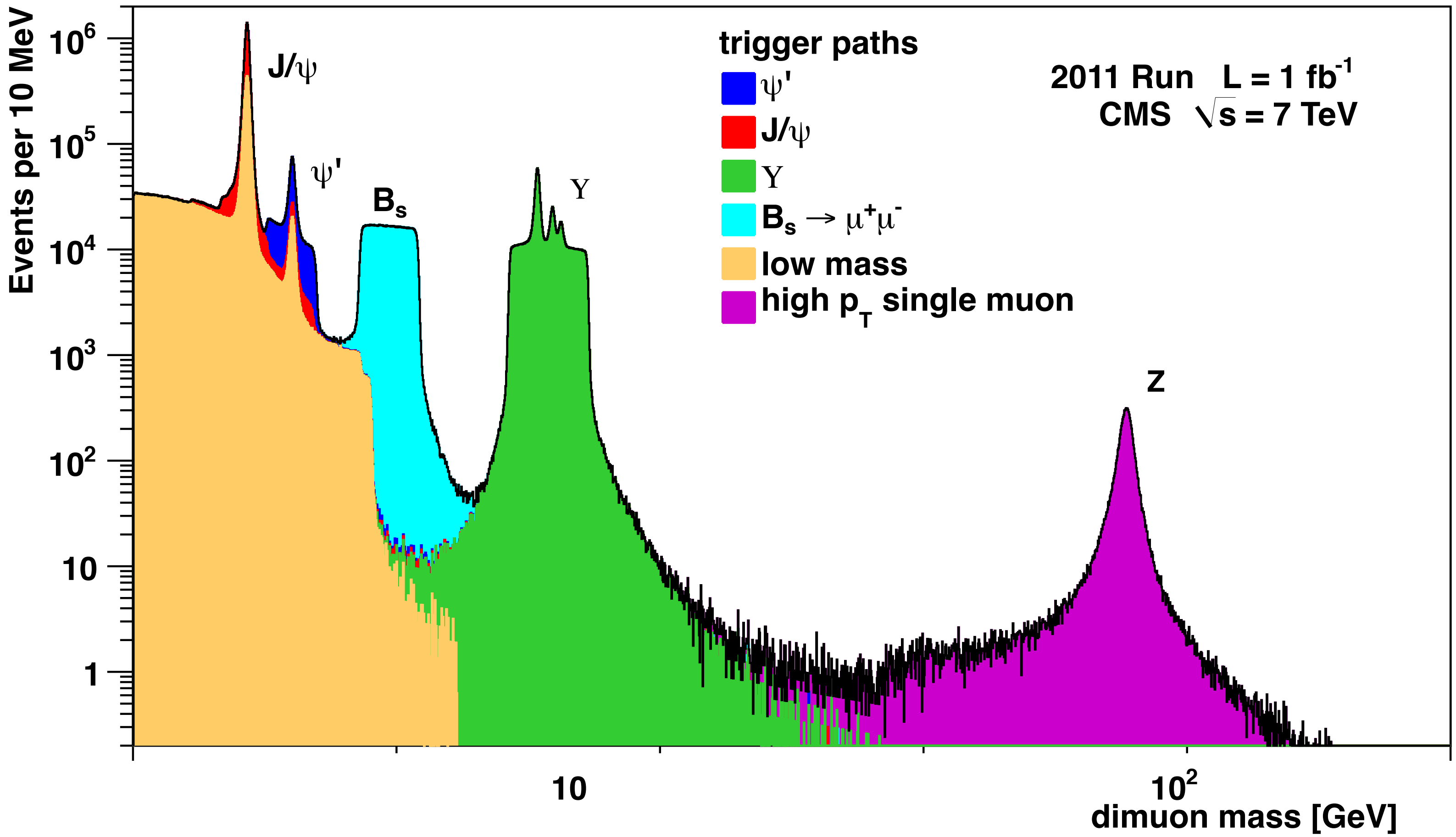


Muon reconstruction efficiency

- Muons reconstructed out to $|\eta|<2.4$ and down to $p_T > 3$ GeV
- Muon identification efficiency plateaus to nearly 100% with turn on at low p_T
- Trigger efficiency plateaus ~85%
- Low muon mis-ID rates measured in data
  - ≈0.1% for π and K
  - ≈0.05% for protons



Heavy flavor triggers

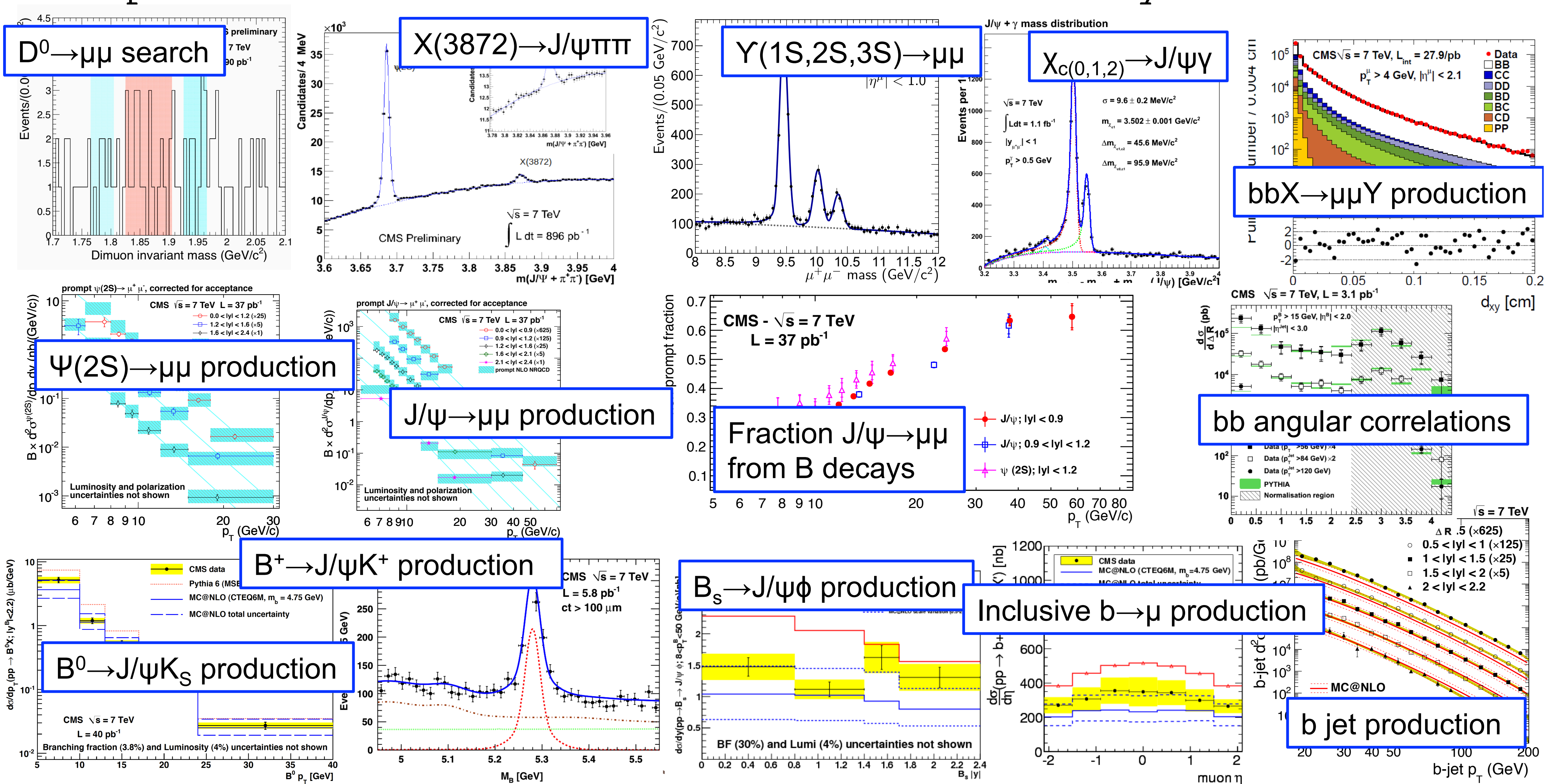


- Use dedicated dimuon trigger paths for heavy flavor studies
- Exploit good momentum, impact parameter, mass and vertex resolution at trigger level to select interesting topologies
- Bandwidth restrictions are the main limitation for most measurements

Things I won't have time for…

- 14 papers from 2 years worth of data and counting…

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH



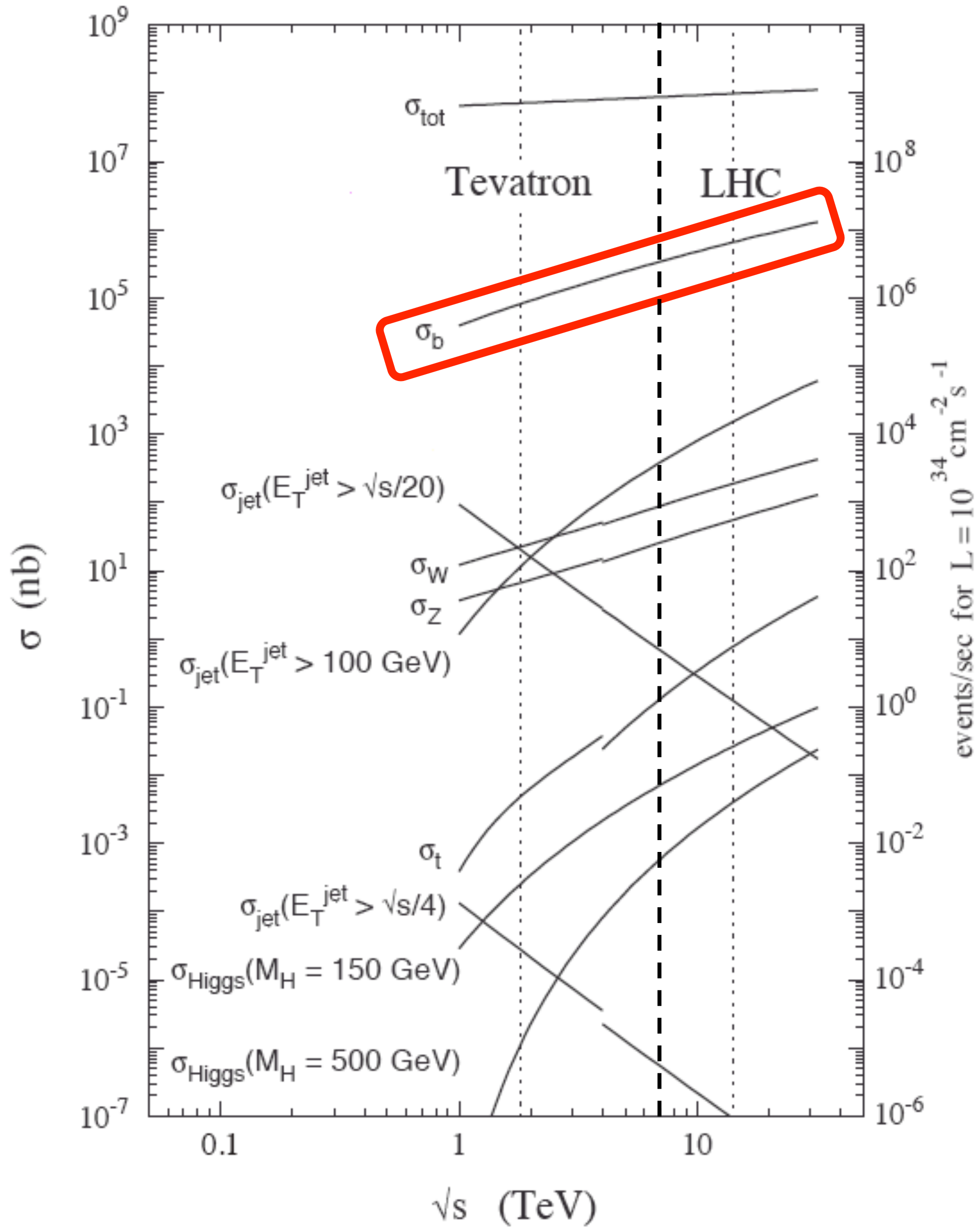
Measurement of Λ_b production

Motivation: b production studies

- LHC opened new energy regime for b production
  - Tests understanding of production dynamics and perturbative QCD
  - Tests extrapolation from Tevatron energies
- b production measurements help model backgrounds for many searches such H→bb or SUSY with b jets

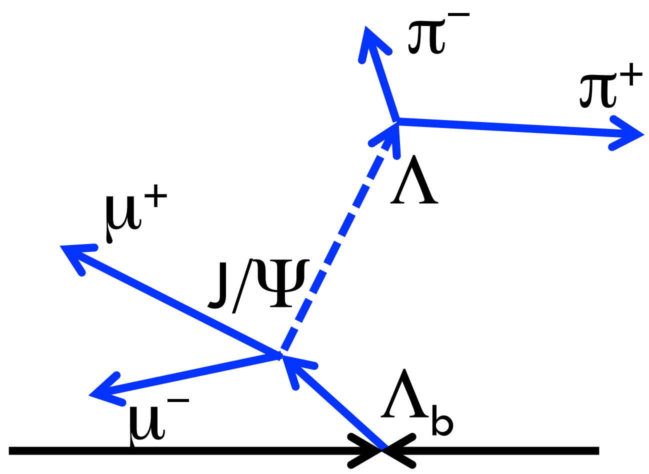
arXiv:1205.6344
Data vs FONLL and NLO MC (POWHEG, MC@NLO)

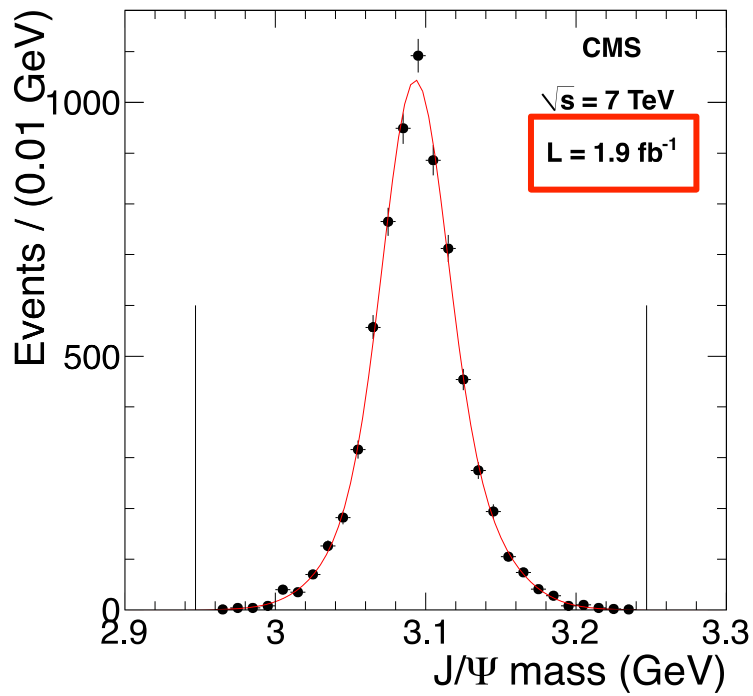
- Λ_b production tests baryon vs meson production differences



Λ_b reconstruction

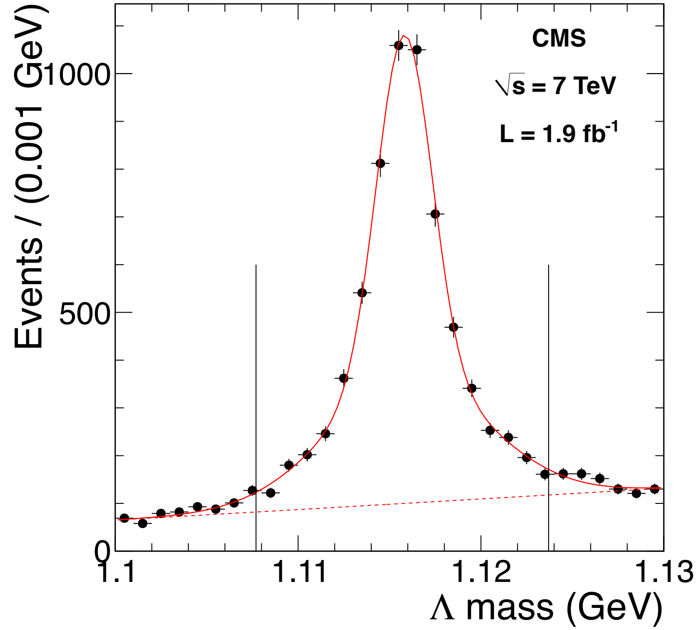
- Λ_b baryons reconstructed in decays to $J/\psi\,\Lambda$
  - $J/\psi \to \mu^+\mu^-$
  - $\Lambda \to p\pi$
- Use $J/\psi \to \mu^+\mu^-$ to trigger events
  - $p_T(\mu^-) > 3.5$ GeV, $|\eta(\mu^-)| < 2.2$
  - Displaced $\mu^+\mu^-$ vertex > 3σ from beamline
  - $p_T(\mu^+\mu^-)$ pointing to beamline
  - Vertex($\mu^+\mu^-$) fit confidence > 10%
- Offline J/ψ cuts only as tight as required by the trigger
- Reduces backgrounds to real displaced J/ψ from b decays

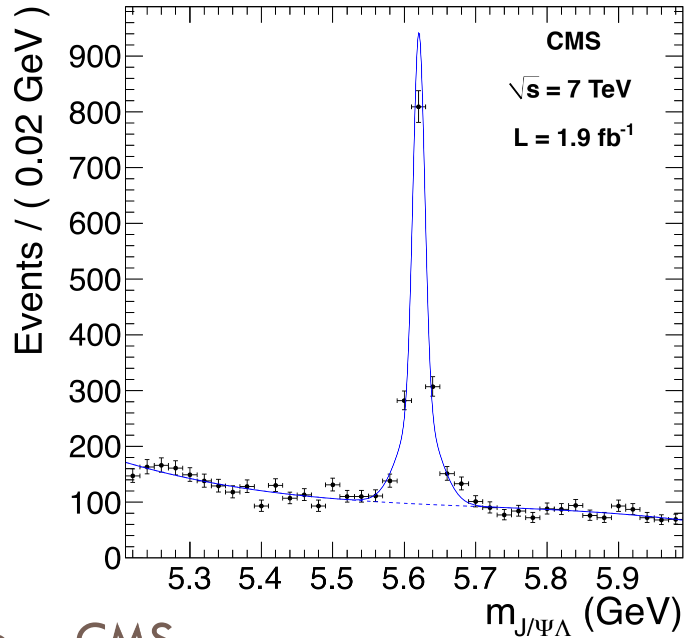




Λ_b reconstruction

- Λ selection
  - Combine good oppositely charged displaced tracks
  - Track $d_0 > 0.5\ \sigma$
  - Vertex $> 5\ \sigma$ from beamline
  - $p_T(p) > 1$ GeV
  - Reject contamination from masses consistent with Ks
- Λ_b selection
  - As loose as possible to keep efficiency high and to probe a broad kinematic range
  - $p_T(\Lambda_b) > 10$ GeV, $|y(\Lambda_b)| < 2.0$
  - Vertex($J/\psi\,\Lambda$) fit confidence > 1%
- Total signal yield = 1252 ± 42





Λ_b cross section measurement

- Slice data in bins in Λ_b p_T and rapidity and fit for signal yields in each
- Determine efficiency in each bin
  - Take factorized approach

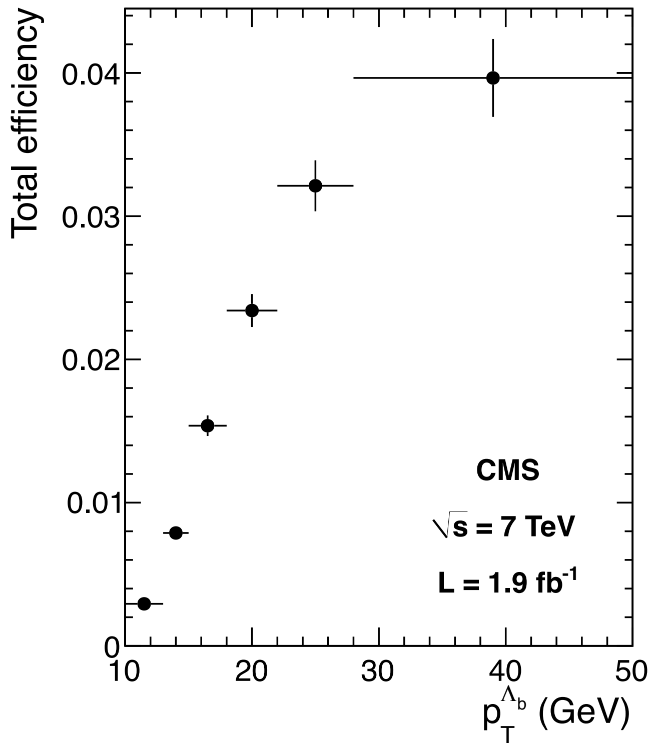
$$\epsilon = \mathcal{A} \cdot \epsilon_{\text{trig}}^{\mu_1} \cdot \epsilon_{\text{trig}}^{\mu_2} \cdot \epsilon_{\text{reco}}^{\mu_1} \cdot \epsilon_{\text{reco}}^{\mu_2} \cdot \epsilon_{\text{trig}}^{\mu\mu} \cdot \epsilon_{\text{sel}}^{\Lambda_b}$$

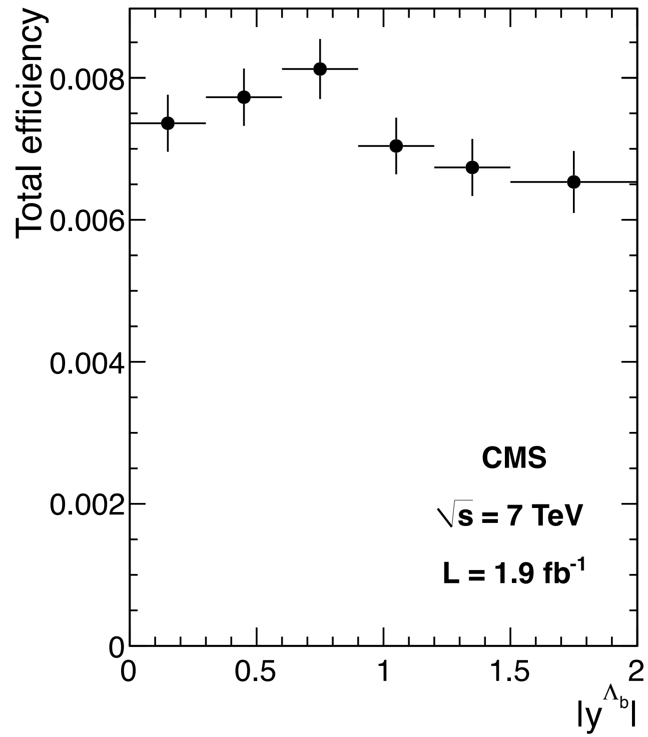
  - Trigger and offline dimuon efficiencies measured in data with "tag and probe" approach
  - Acceptance and Λ and Λ_b selection cuts measured in simulation
    - Reweight MC to match data pileup distribution and Λ_b p_T and y distributions

$p_T^{\Lambda_b}$ (GeV)	n_{sig} events	ϵ (%)
$10-13$	293 ± 22	0.29 ± 0.03
$13-15$	240 ± 18	0.79 ± 0.08
$15-18$	265 ± 19	1.54 ± 0.16
$18-22$	207 ± 16	2.34 ± 0.23
$22-28$	145 ± 14	3.21 ± 0.34
$28-50$	87 ± 11	3.96 ± 0.50
$\lvert y^{\Lambda_b}\rvert$	n_{sig} events	ϵ (%)
$0.0-0.3$	233 ± 17	0.74 ± 0.09
$0.3-0.6$	256 ± 18	0.77 ± 0.09
$0.6-0.9$	206 ± 16	0.81 ± 0.09
$0.9-1.2$	196 ± 17	0.70 ± 0.08
$1.2-1.5$	189 ± 17	0.67 ± 0.09
$1.5-2.0$	162 ± 18	0.65 ± 0.09

Λ_b cross section measurement

- Efficiency rises rapidly vs p_T, mostly flat vs y
- Biggest efficiency losses from
  - Λ reco (10-16% efficient)
  - Dimuon acceptance (12-63% efficient)
  - Displaced dimuon trigger (33-56% efficient)
- Total integrated efficiency = 0.7%
- Efficiency ratio also considered for asymmetry measurement $\frac{\epsilon(\Lambda_b)}{\epsilon(\overline{\Lambda}_b)}$
  - Lower $\bar{p}$ efficiency from more interactions

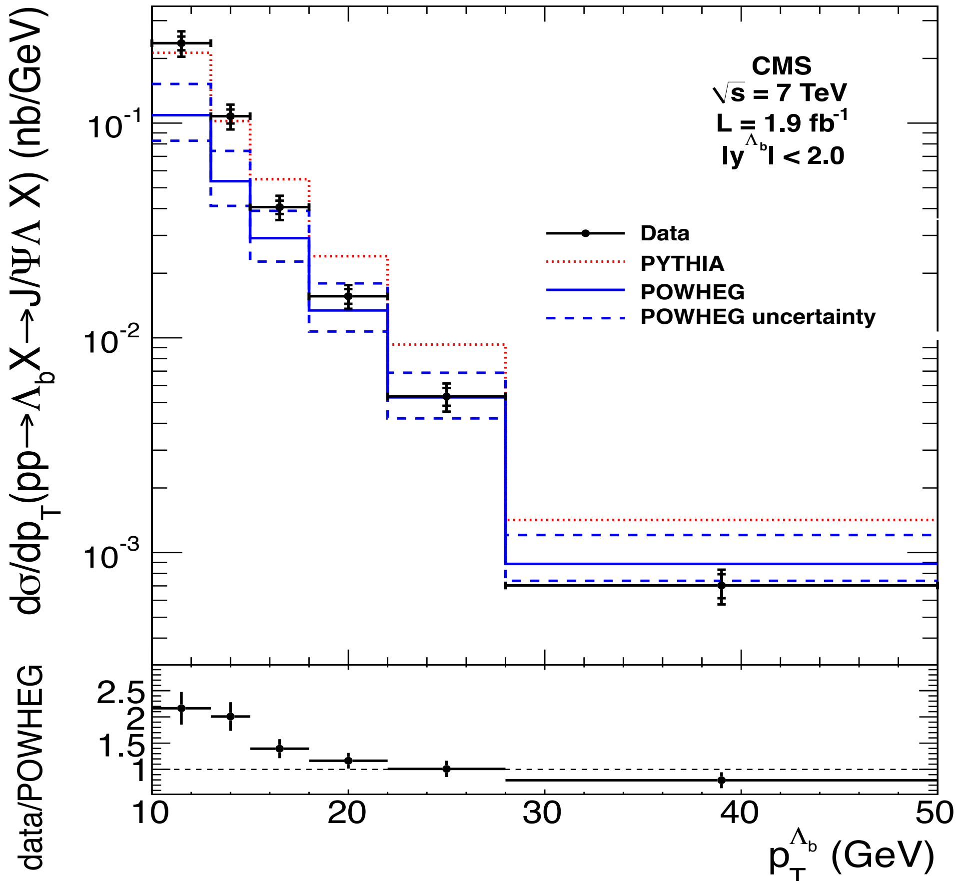


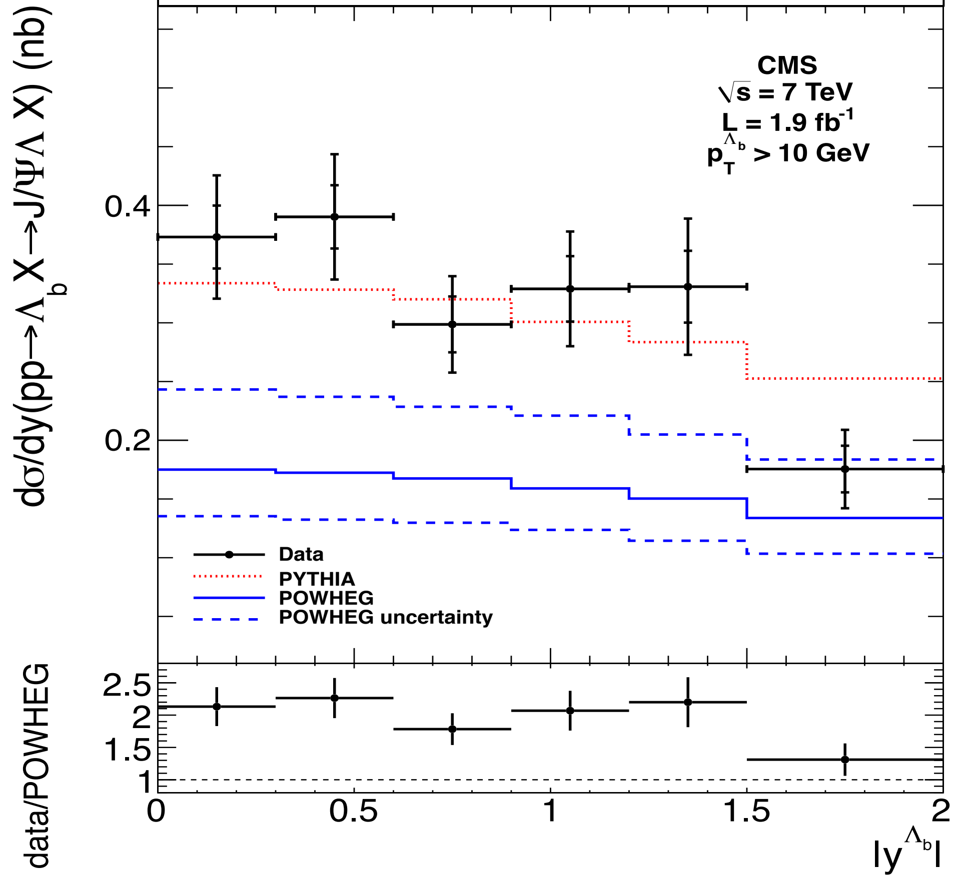


Λ_b cross section results

- Measure cross section by dividing yields by efficiency and luminosity
  - 54% uncertainty on BF($\Lambda_b \rightarrow J/\psi\Lambda$), so report $\sigma(pp \rightarrow \Lambda_b X)$*BR($\Lambda_b \rightarrow J/\psi\Lambda$)

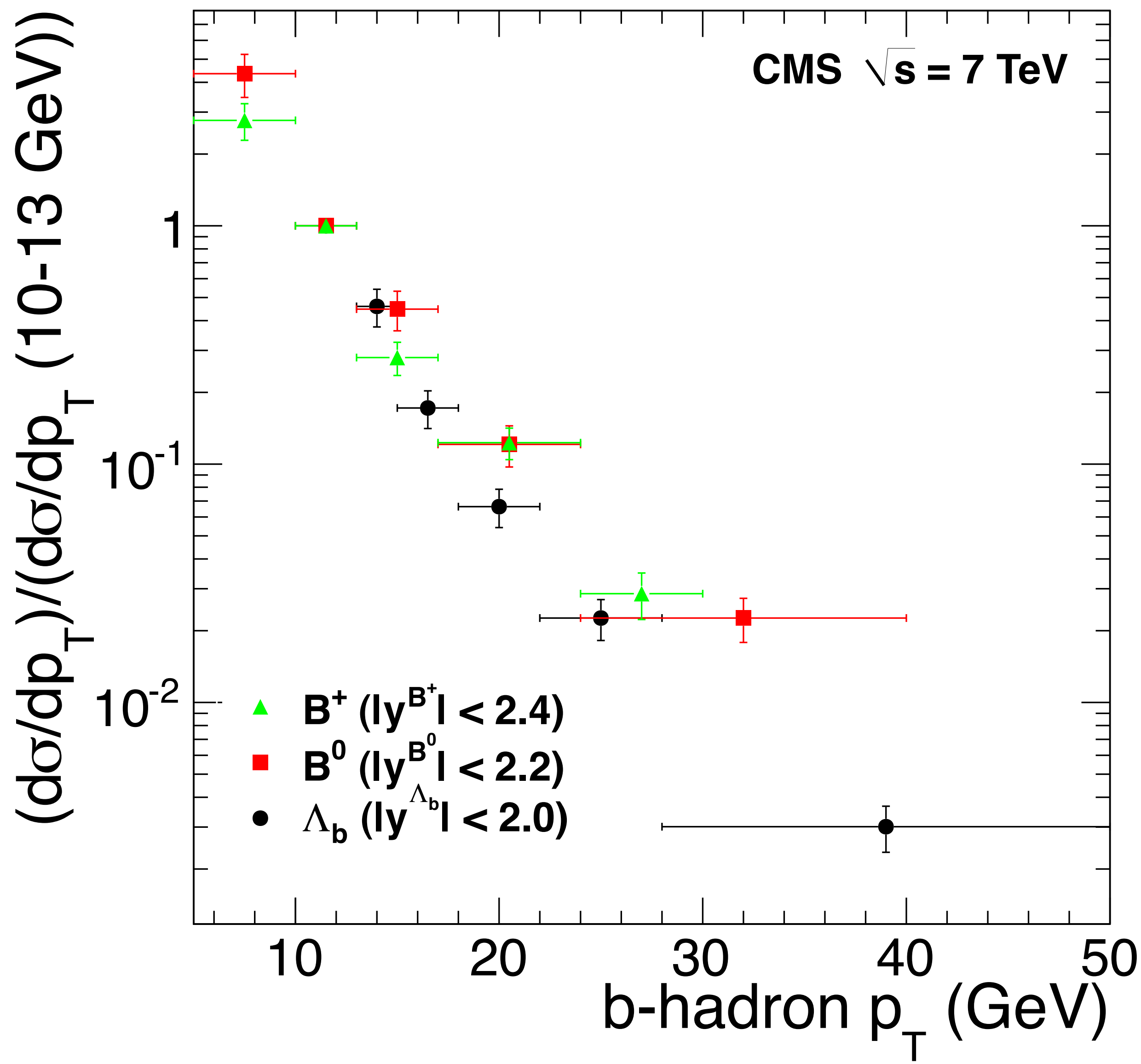
arXiv:1205.0594, accepted by PRL





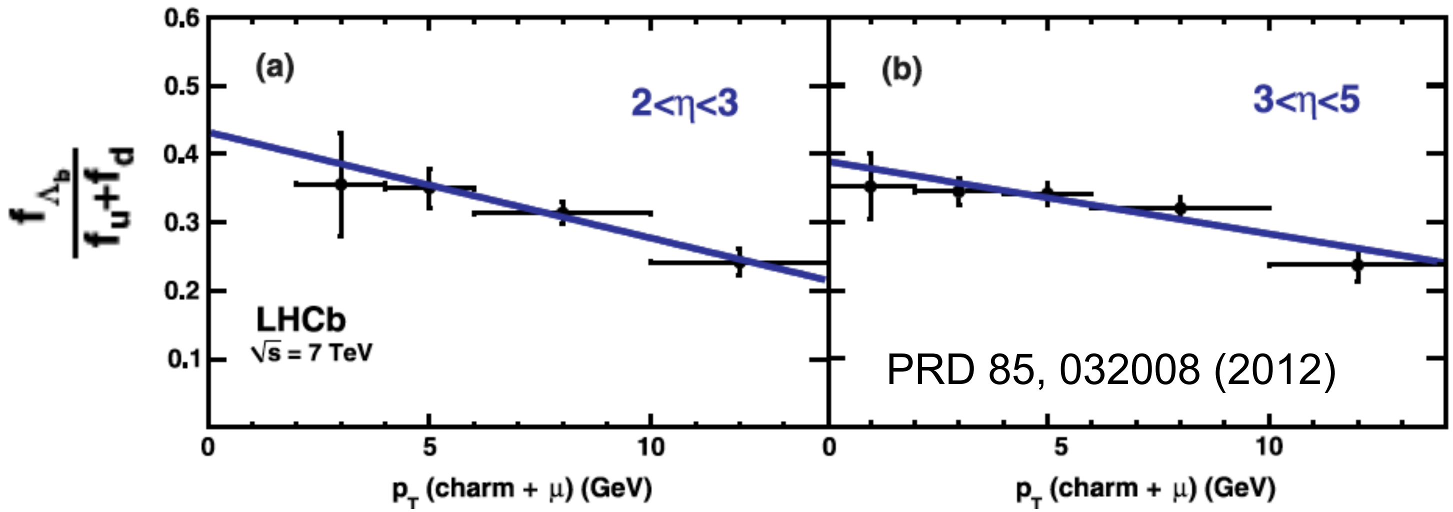
Λ_b cross section compared to mesons

- Similar measurements have been made for B^+, B^0 and B_s mesons
- Shape vs B p_T shows interesting feature
  - Baryon spectrum falls faster than meson spectra
  - Same underlying b quark production spectra
  - Something happening in baryon vs meson hadronization



Λ_b cross section compared to mesons

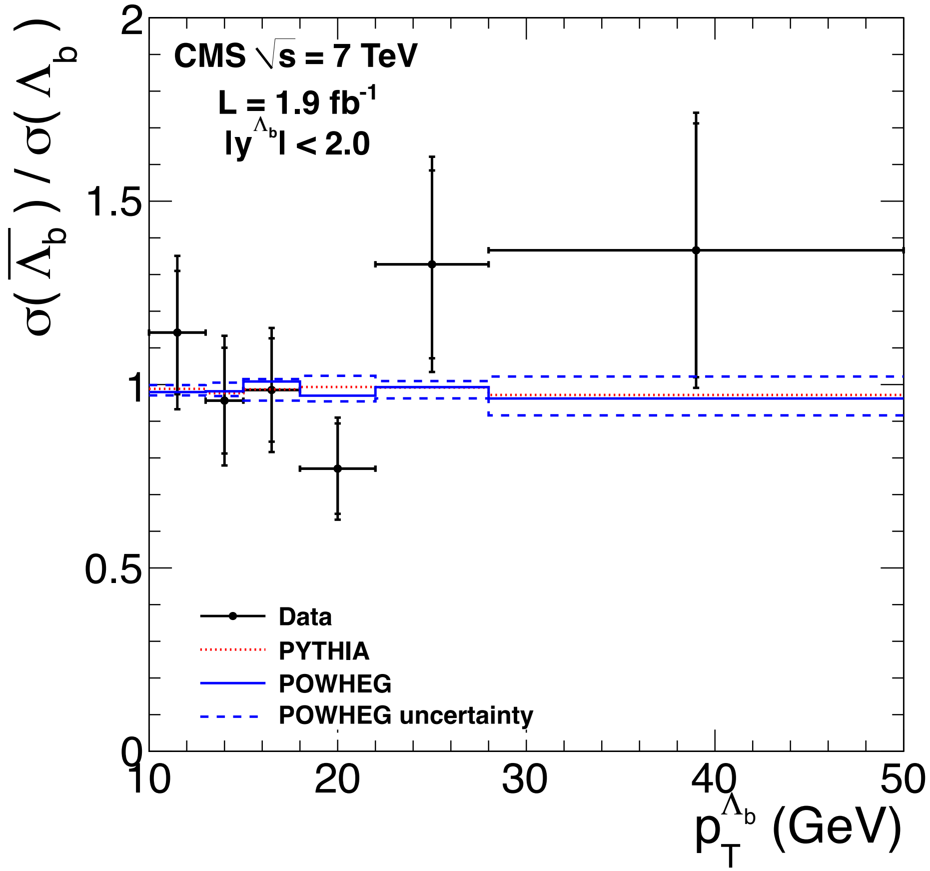
- Similar feature observed by LHCb in measurement of $f_{\Lambda b}/(f_u+f_d)$ vs momentum

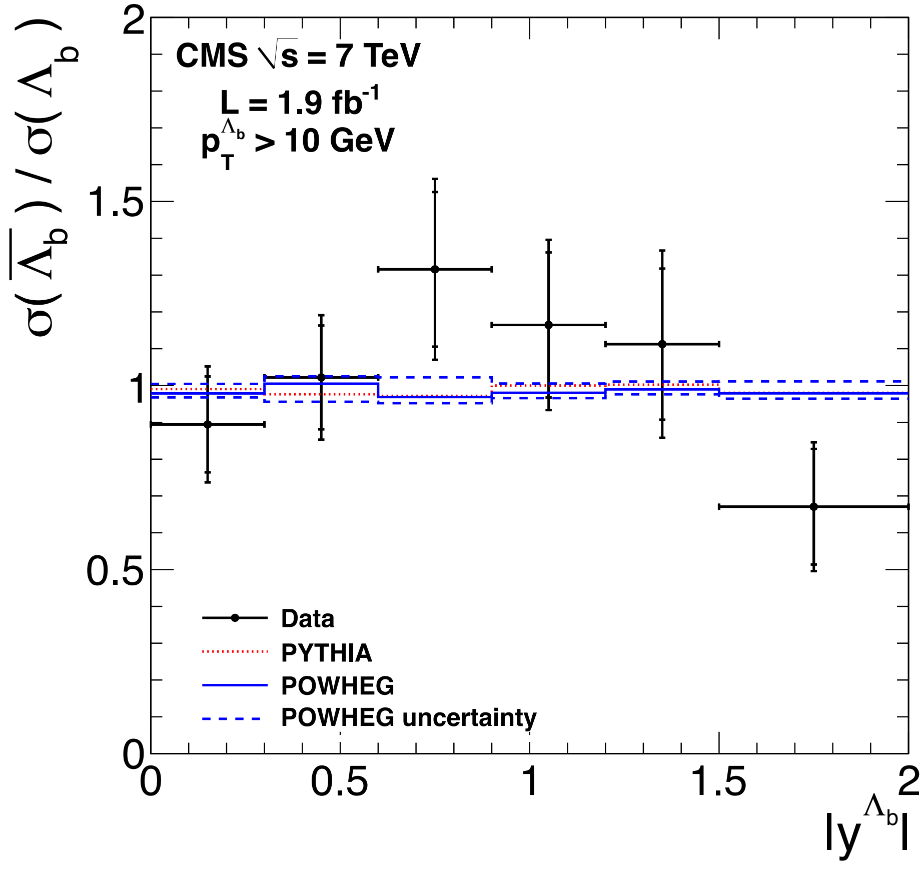


- Historically, hadronization fractions assumed to be constant
- However, measurements between LEP and Tevatron not consistent
  - HFAG 2012: Tevatron (p_T(b) ~10 GeV): f(b-baryon) = 0.212 ± 0.069
  - HFAG 2012: LEP (p_T(b) ~40 GeV): f(b-baryon) = 0.090 ± 0.015
- Discrepancy in baryon/meson production measurements between Tevatron and LEP could be explained by different p_T spectra

$\overline{\Lambda}_b / \Lambda_b$ asymmetry results

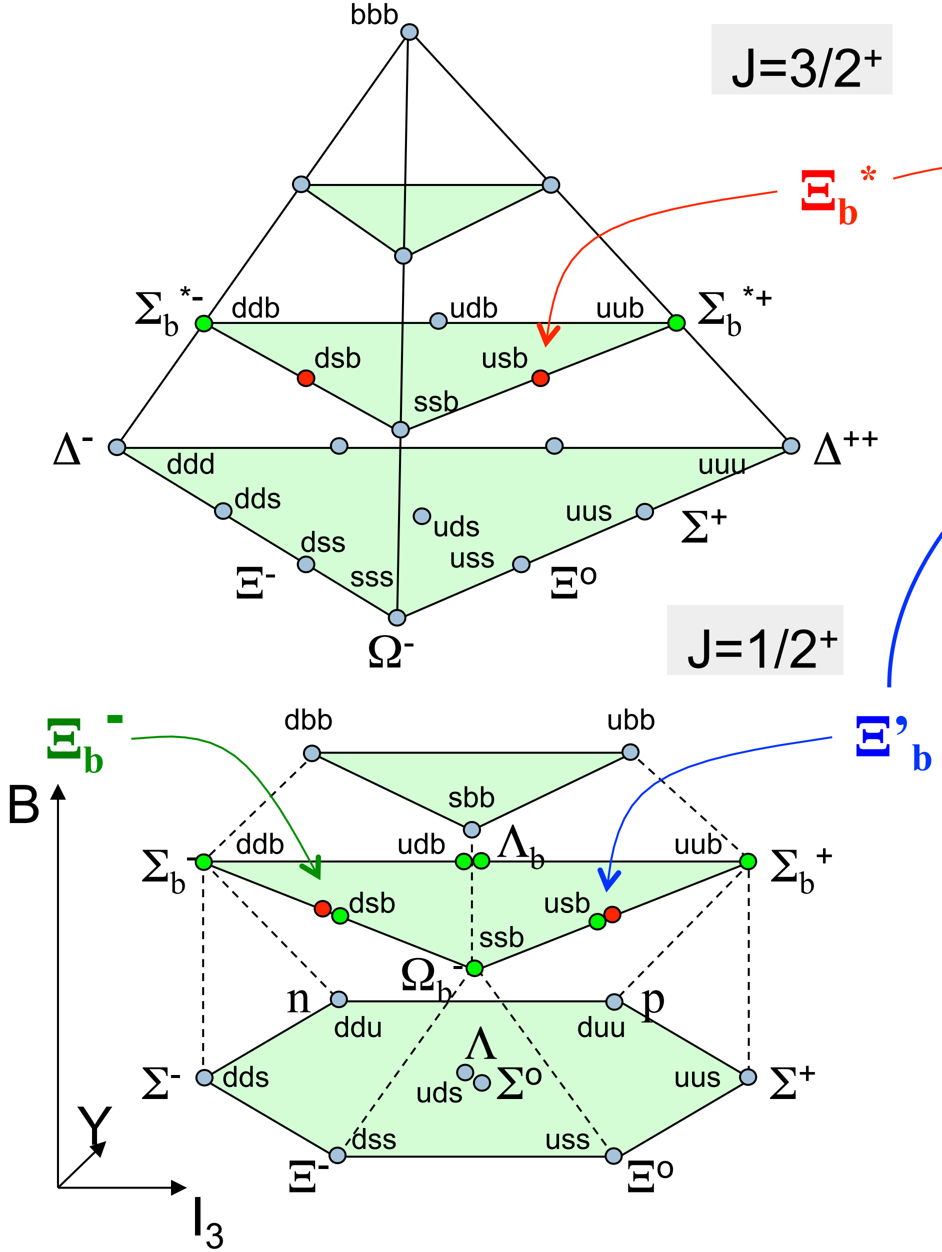
- Also measure yields and efficiencies as ratios between particles and antiparticles
  - Use charge of higher momentum Λ track to identify the (anti)proton
- Results consistent with no asymmetry, within large uncertainties
- Tests baryon transport models from initial pp state

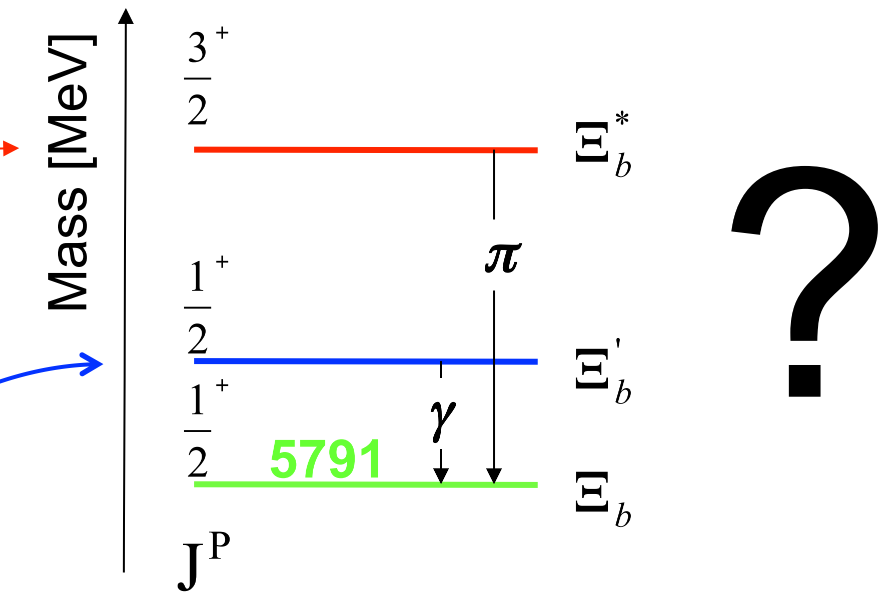




Discovery of Ξ_b^* baryon

b baryon states





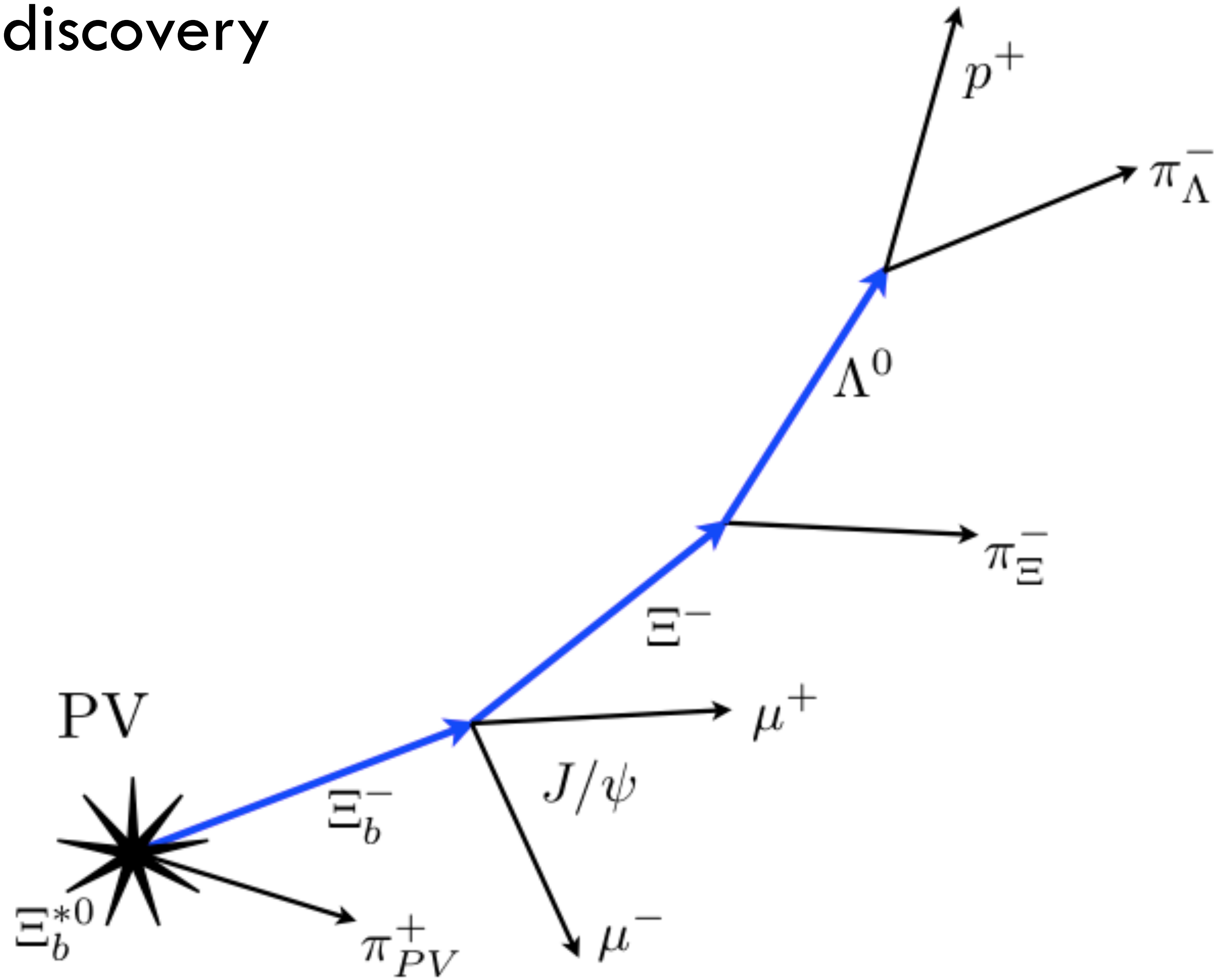
- New state: $\Xi_b^{?0} \rightarrow \Xi_b^- \pi^+$
- $\Xi_b^{'0}$ and Ξ_b^{*0} are candidates
- By analogy to charm sector, Ξ_b^{*0} mass splitting expected > m_π
- Believe new state is Ξ_b^{*0} with J=3/2+
- Still lots left out there…

Press for Ξ_b^* baryon discovery

Press for Ξ_b^* baryon discovery

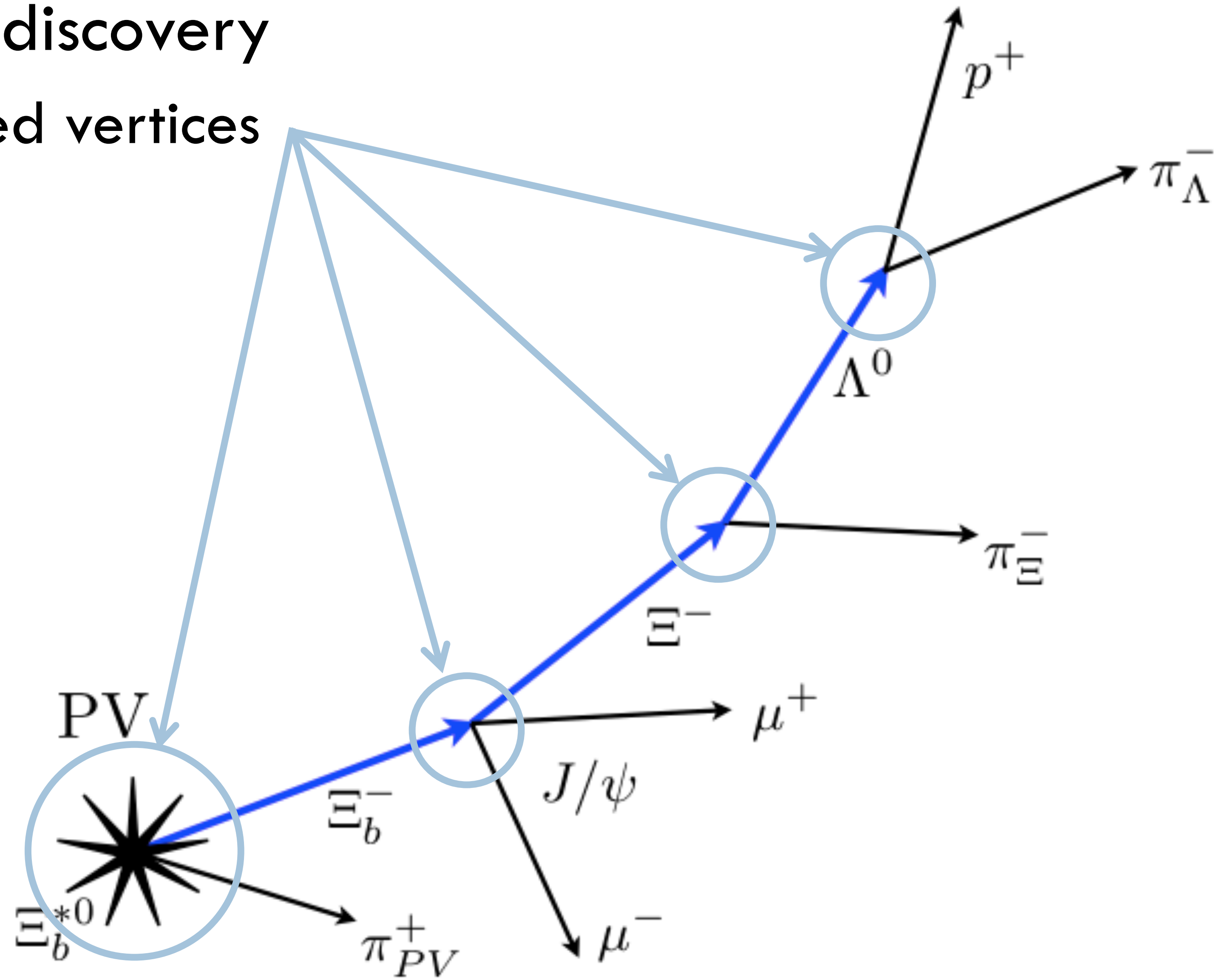
Discovery of Ξ_b^* baryon

- Anatomy of a discovery



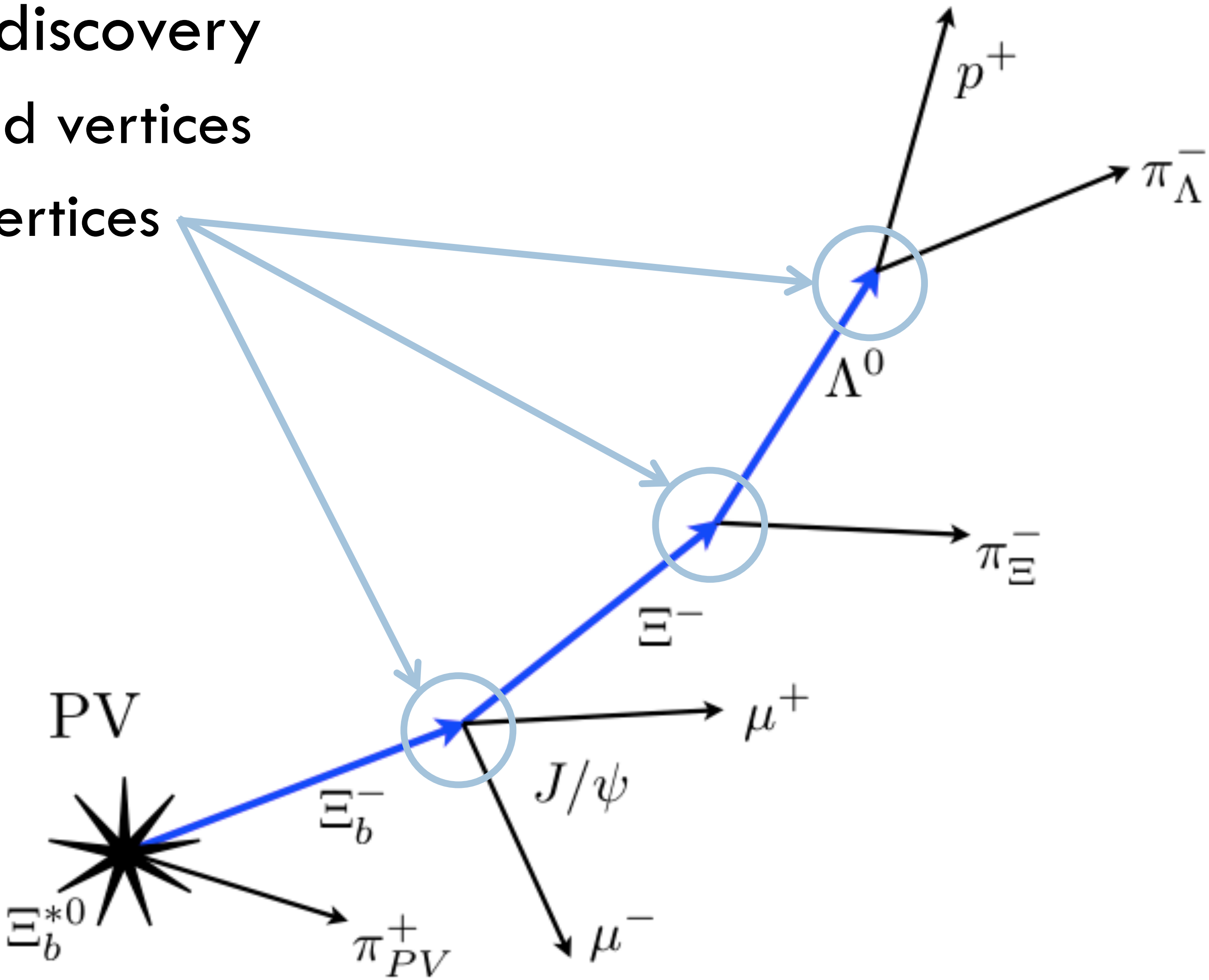
Discovery of Ξ_b^* baryon

- Anatomy of a discovery
  - 4 reconstructed vertices



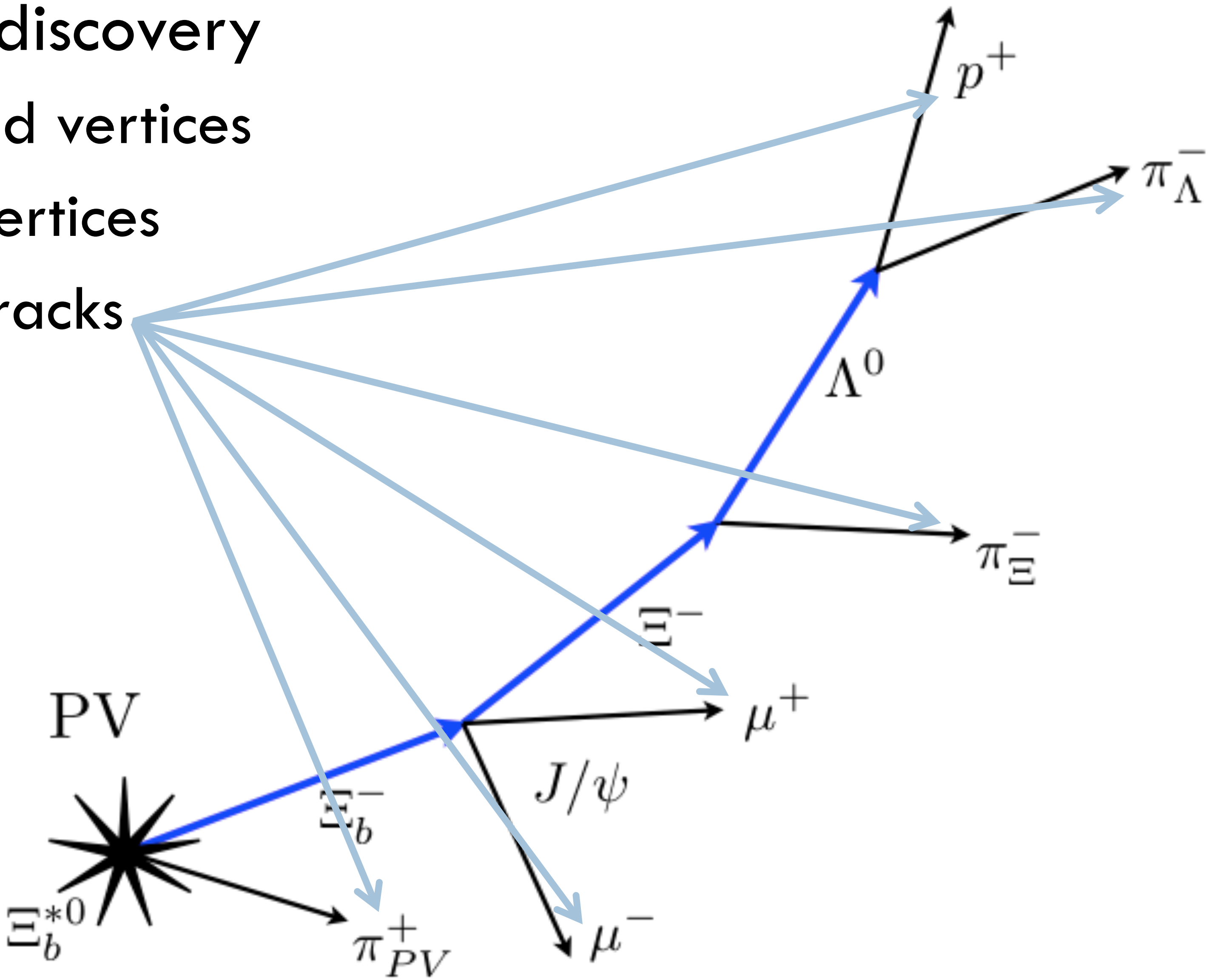
Discovery of Ξ_b^* baryon

- Anatomy of a discovery
  - 4 reconstructed vertices
  - 3 displaced vertices



Discovery of Ξ_b^* baryon

- Anatomy of a discovery
  - 4 reconstructed vertices
  - 3 displaced vertices
  - 6 final state tracks

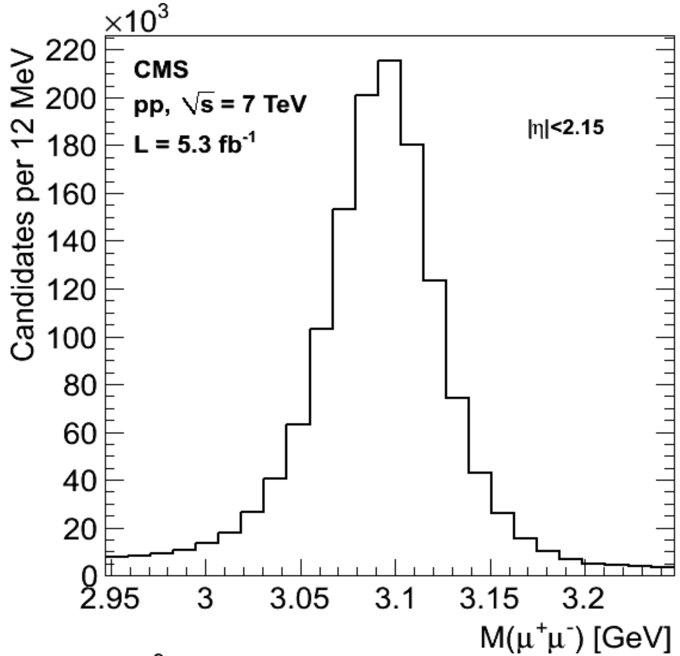


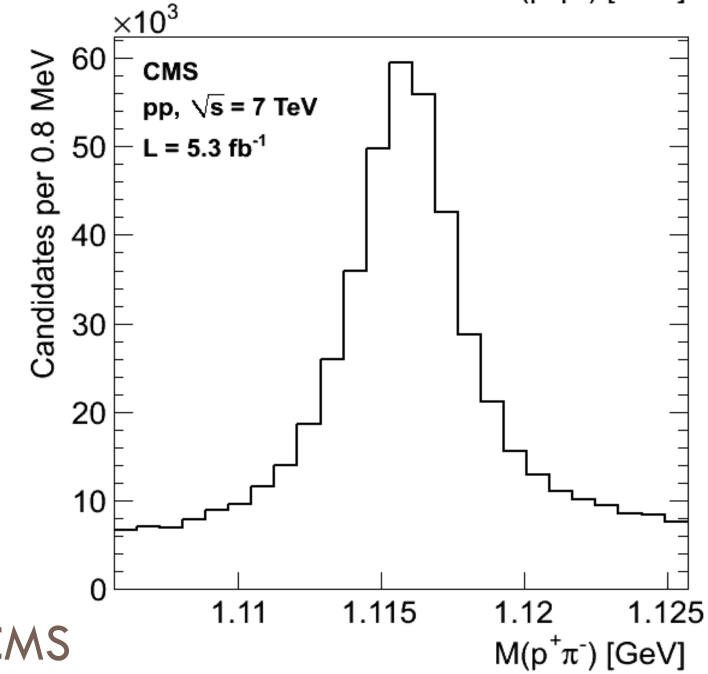
Ξ_b^* reconstruction

- Search strategy to maximize Ξ_b^- yield
  - Still a complicated decay chain itself

$$\Xi_b^- \to J/\Psi(\mu^-\mu^+)\Xi^-(\Lambda\pi^-), \text{ with } \Lambda \to p\pi^-$$

- OR of two J/ψ triggers used
  - Displaced trigger as in $\Lambda_b \to J/\psi\,\Lambda$ analysis
  - Prompt trigger with $p_T(\mu^+\mu^-) > 13$ GeV and $\eta(\mu^+\mu^-) < 1.25$
- Λ reconstructed as in $\Lambda_b \to J/\psi\,\Lambda$ but with 10σ vertex displacement





Ξ_b^* reconstruction

Ξ_b^- first observed here by
D0 PRL 99, 052001 (2007)
and CDF PRL 99, 052002 (2007)

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  - Still a complicated decay chain itself

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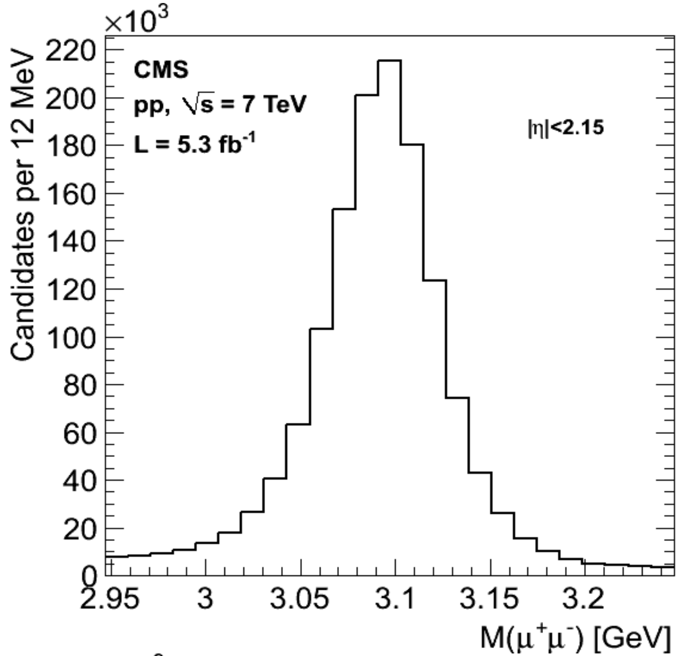
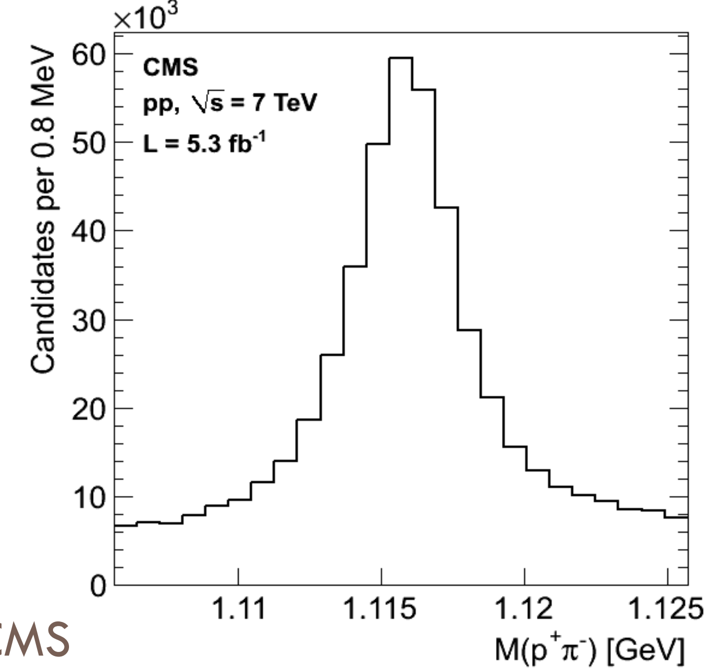
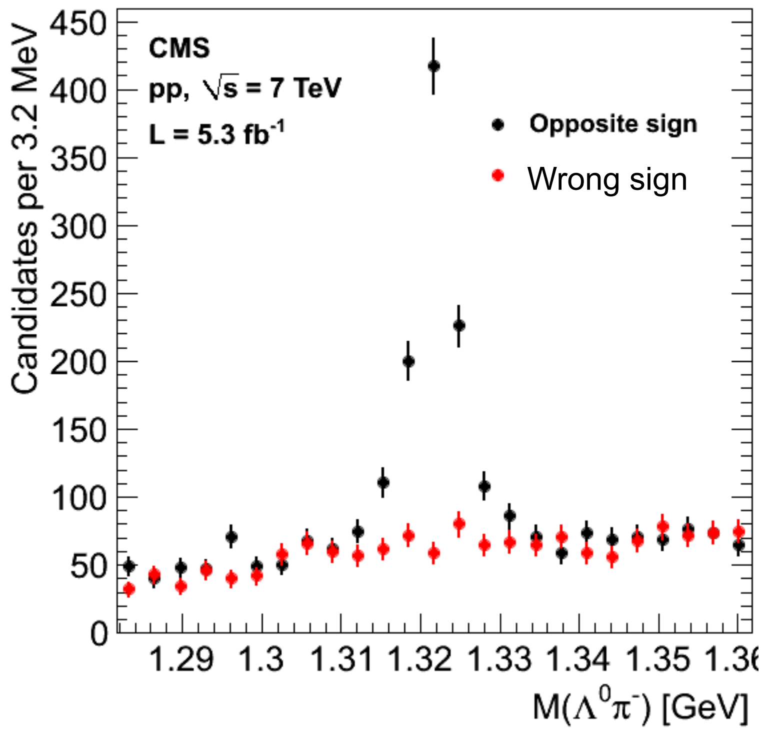
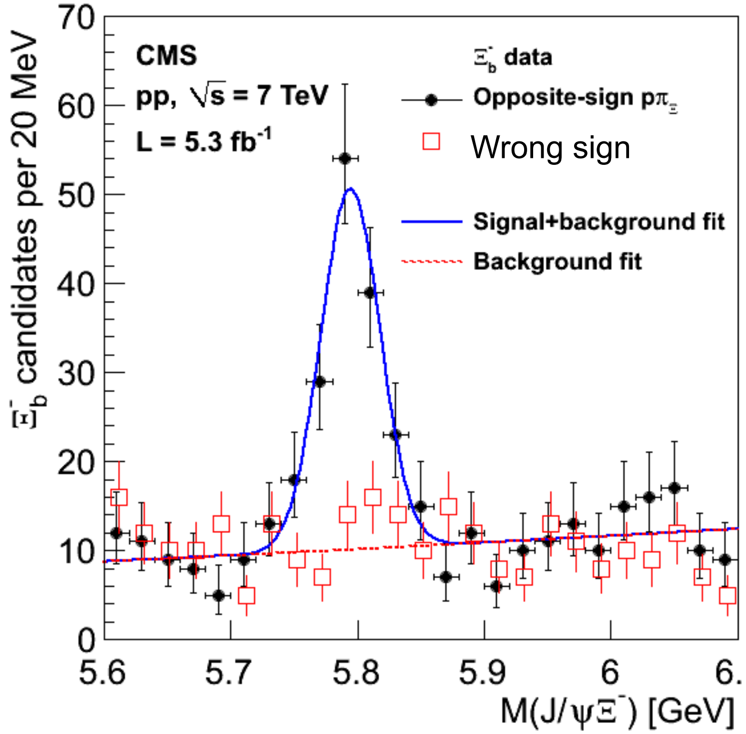




Ξ_b^- reconstruction

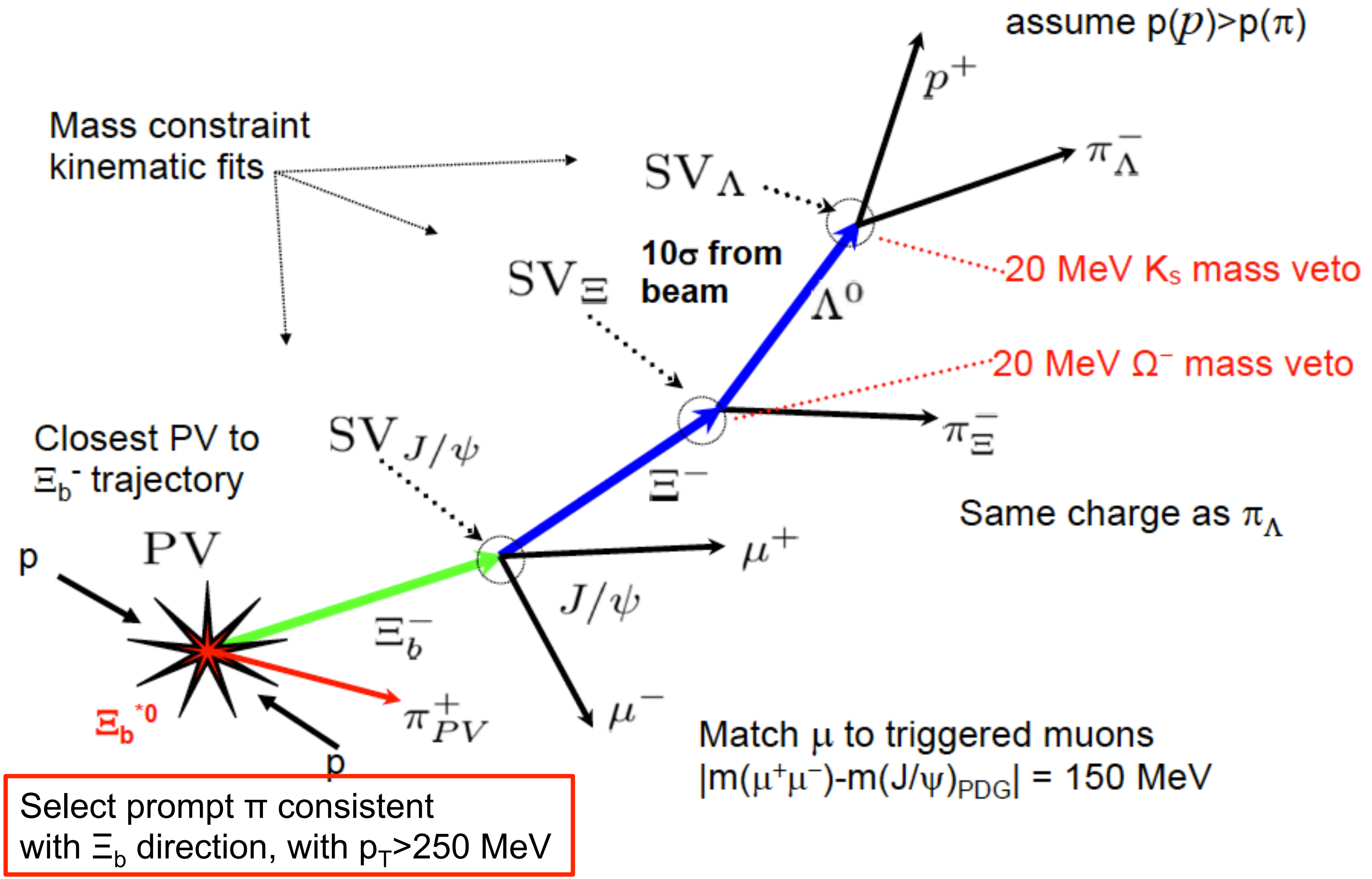
- Ξ^- candidates reconstructed from $\Lambda\pi$ pairs
- Ξ_b candidates reconstructed from $J/\psi\,\Xi^-$ pairs





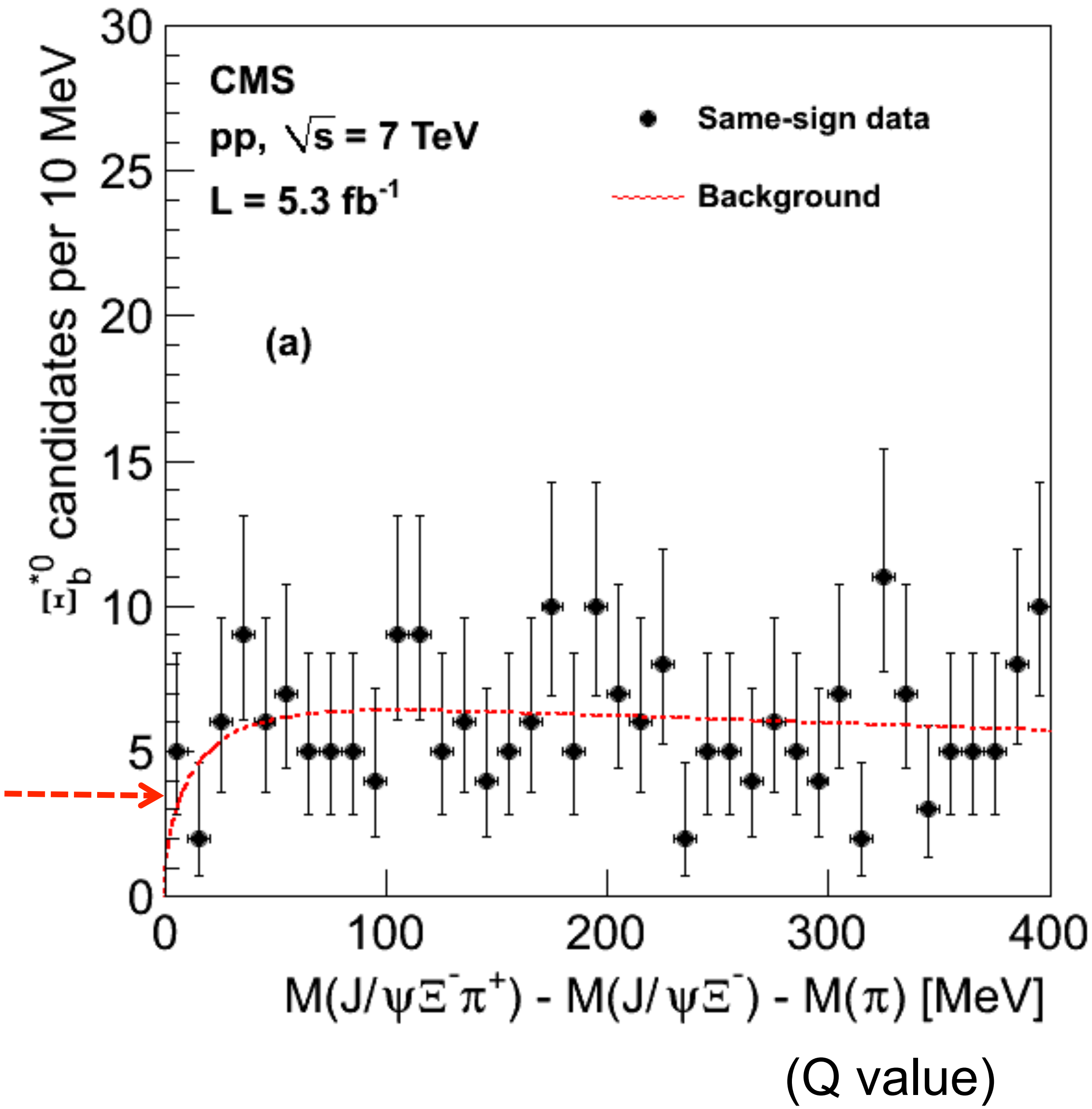
- Final selection cuts determined with optimization algorithm on data
  - Randomly varying selection and keeping better combination
  - Select on track d_0/σ, vertex displacement significance, pointing angles, vertex confidences, and track and resonance p_T
  - 30 variables in total

Putting it all together



Ξ_b^* background shape

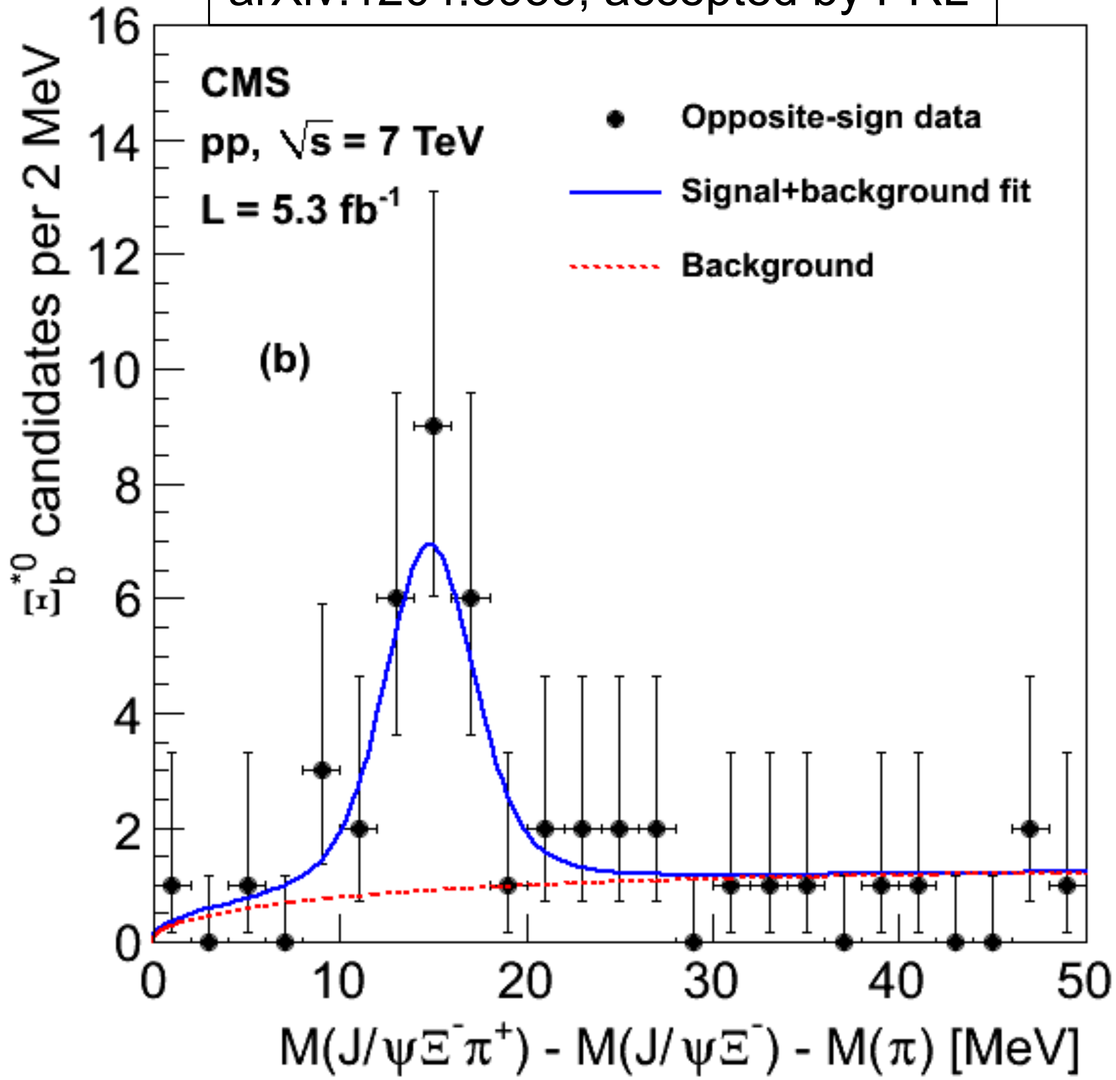
- Background dominated by random $\Xi_b \pi^+$
- Background shape from wrong sign pions
  - Toy model from data shapes for p(Ξ_b), p(π) and angle between Ξ_b and π, assumed to be uncorrelated
  - Fit toy results for shape
  - Compares well with nominal wrong sign distribution



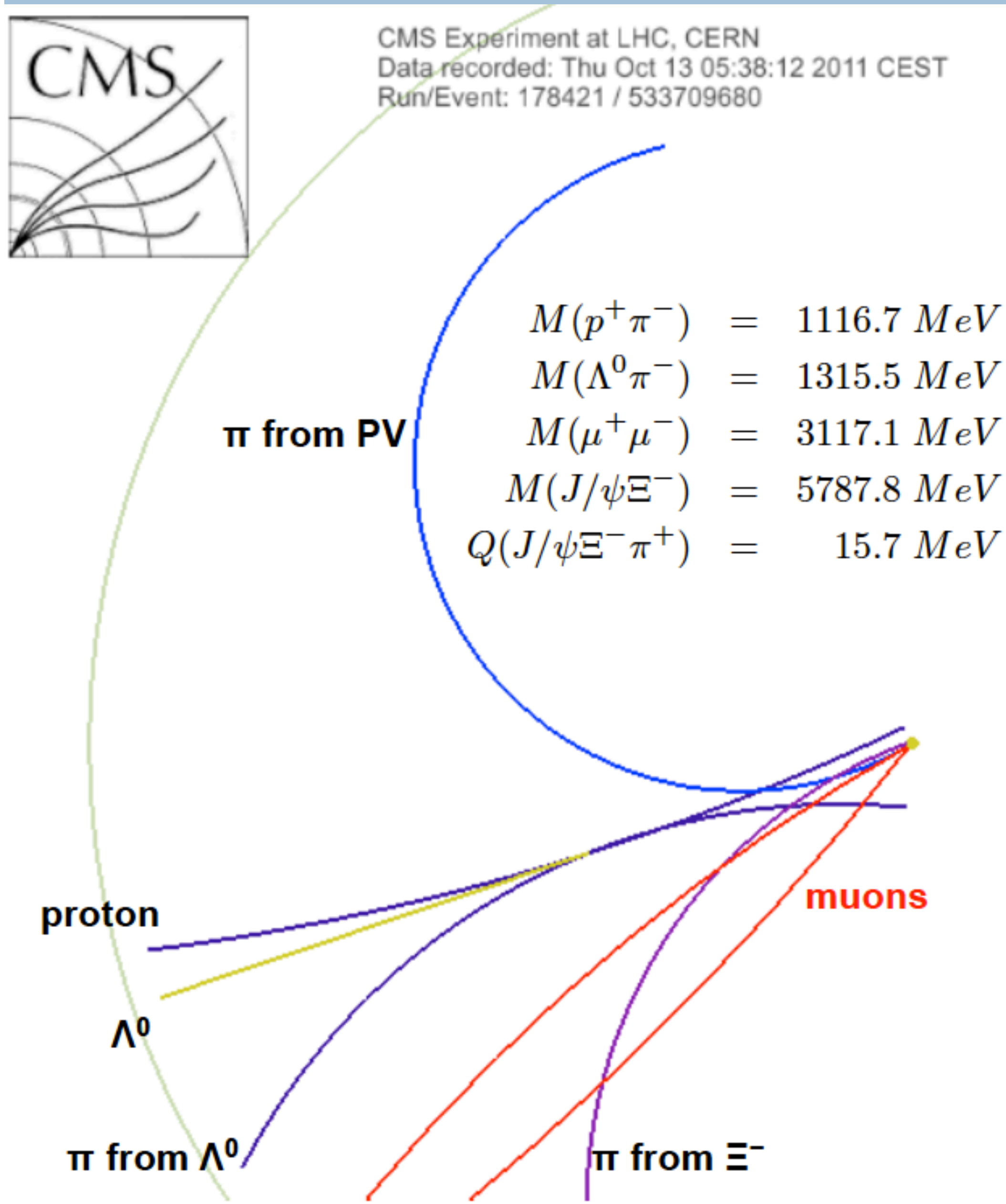
Ξ_b^* signal

- 21 events observed with 12 < Q < 18 MeV
  - 3.0 ± 1.4 background events expected
- Signal fit with Gaussian convolved with BW
  - Gaussian fixed to expected resolution of 1.9 MeV from simulation
  - Width measured as 2.1 ± 1.7 (stat.) MeV
- Q = 14.8 ± 0.7 ± 0.3 MeV
- m(Ξ_b^*) = 5945.0 ± 0.7 ± 0.3 ± 2.7 (PDG) MeV
- Significance determination from $\ln(\mathcal{L}_{s+b}/\mathcal{L}_b) = 6.9\sigma$
- Confirmed with toys varying backgrounds within uncertainties including LEE = 5.7σ

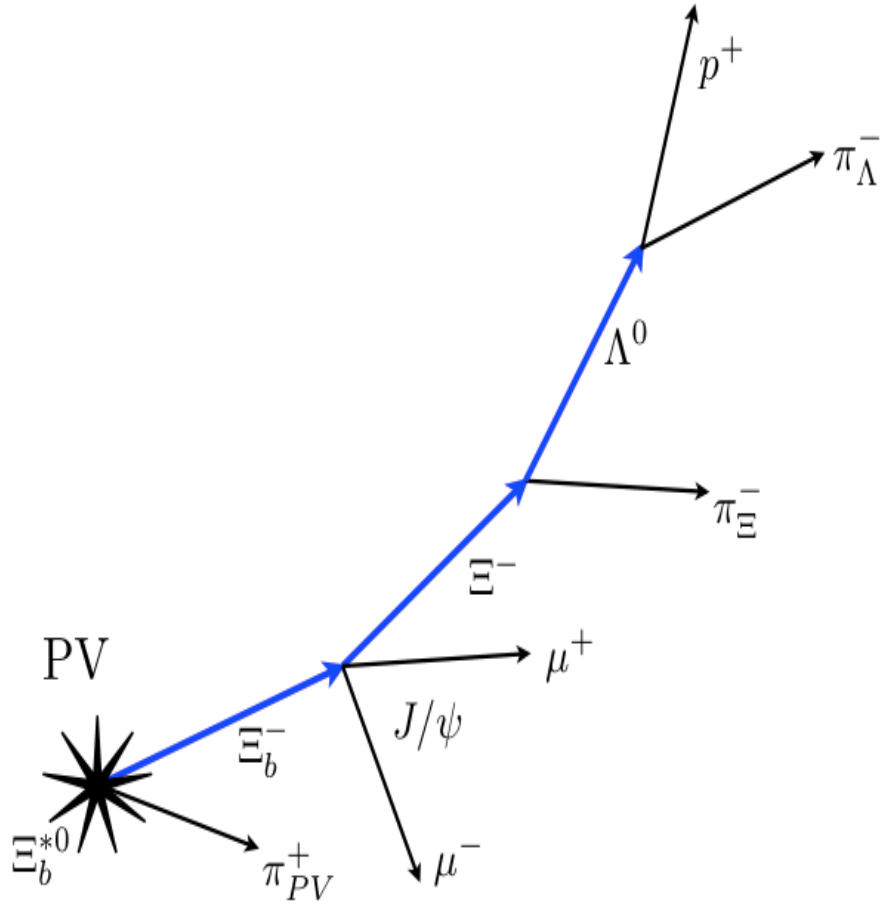
arXiv:1204.5955, accepted by PRL



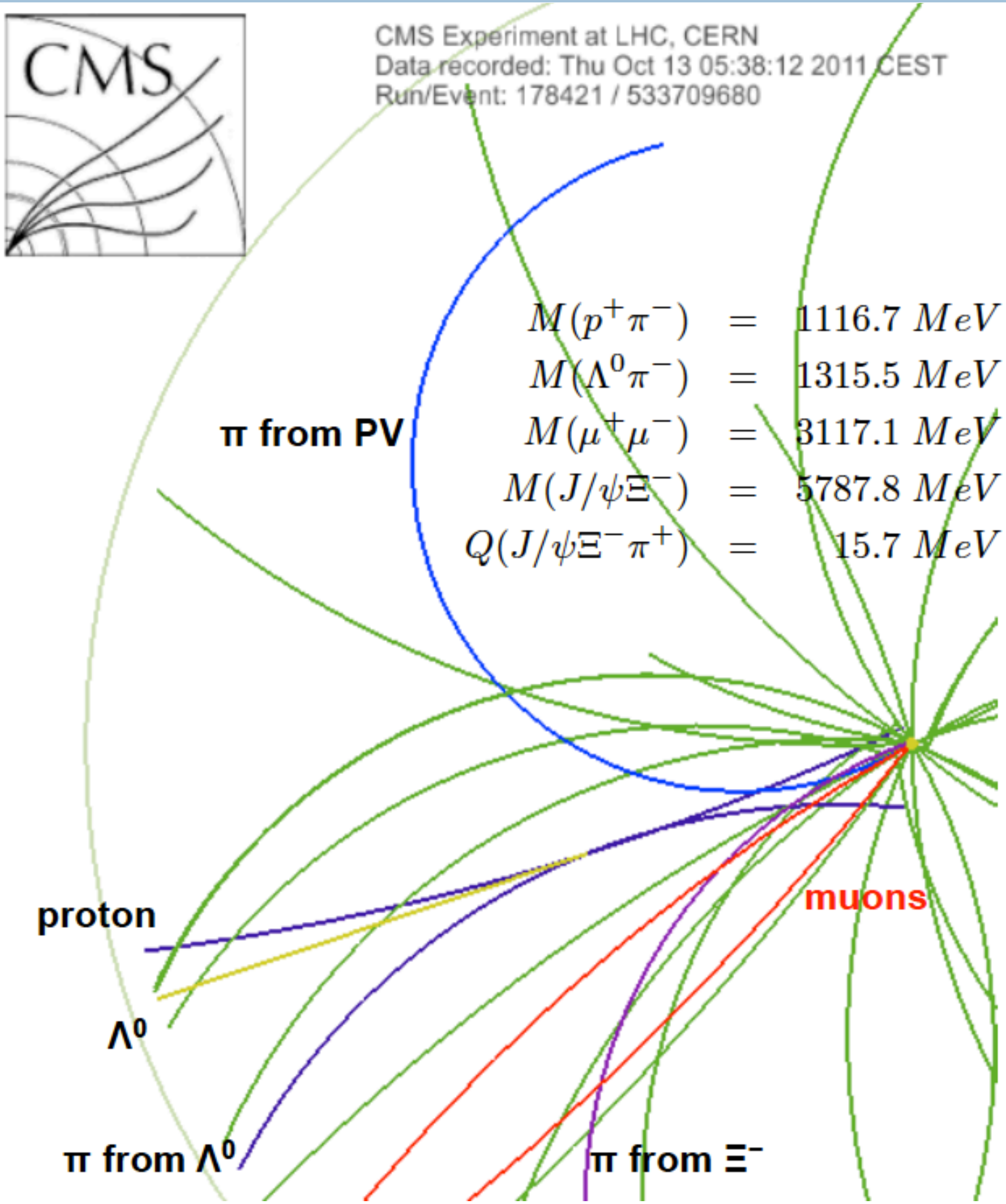
What it really looks like

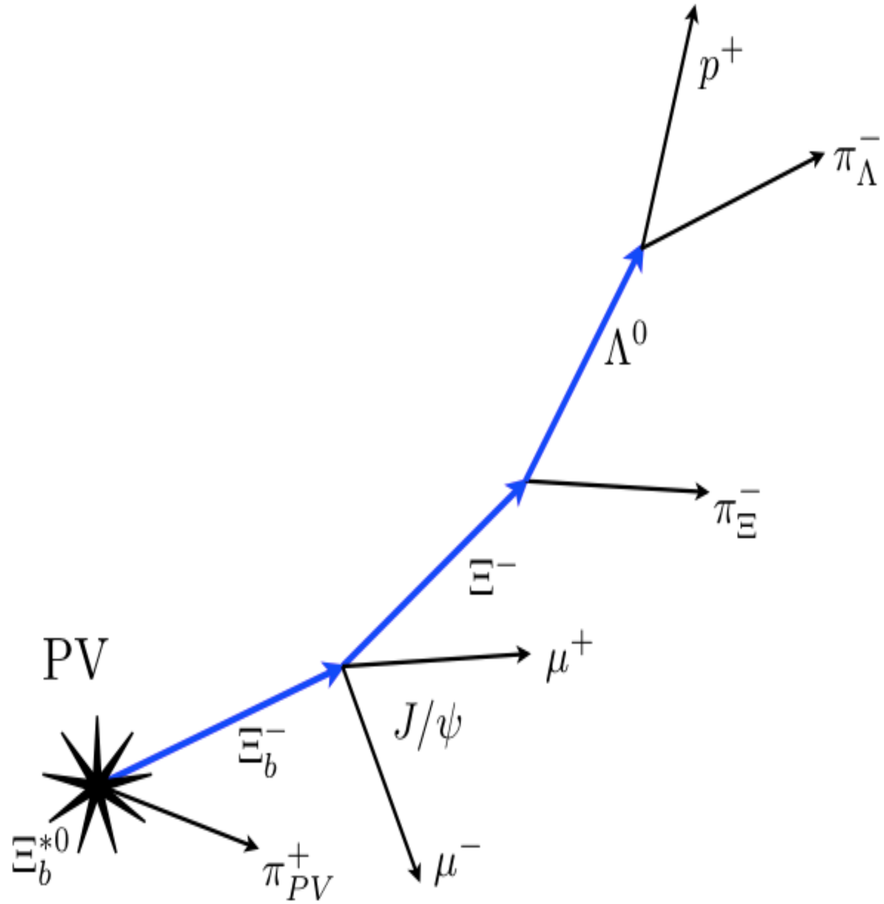


$$
\begin{aligned}
M(p^+\pi^-) &= 1116.7\ MeV\\
M(\Lambda^0\pi^-) &= 1315.5\ MeV\\
M(\mu^+\mu^-) &= 3117.1\ MeV\\
M(J/\psi\Xi^-) &= 5787.8\ MeV\\
Q(J/\psi\Xi^-\pi^+) &= 15.7\ MeV
\end{aligned}
$$



What it really, really looks like





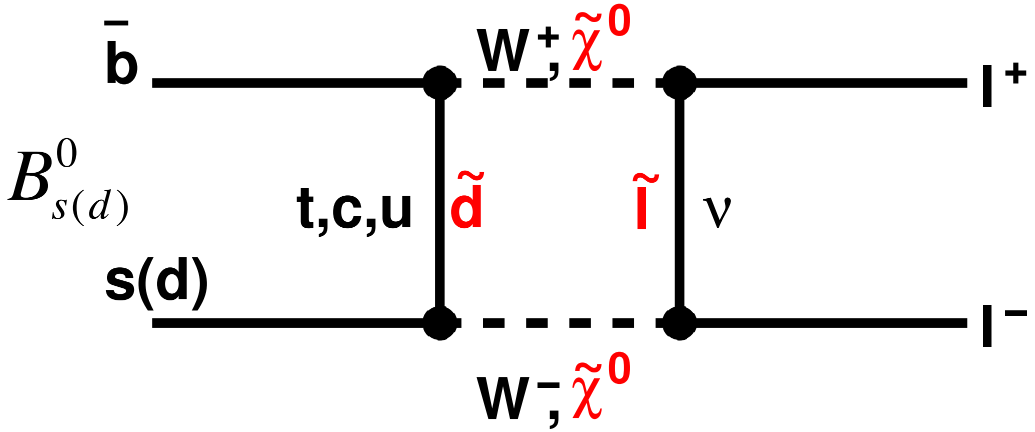
Search for $B^0_{(s)} \to \mu^+\mu^-$

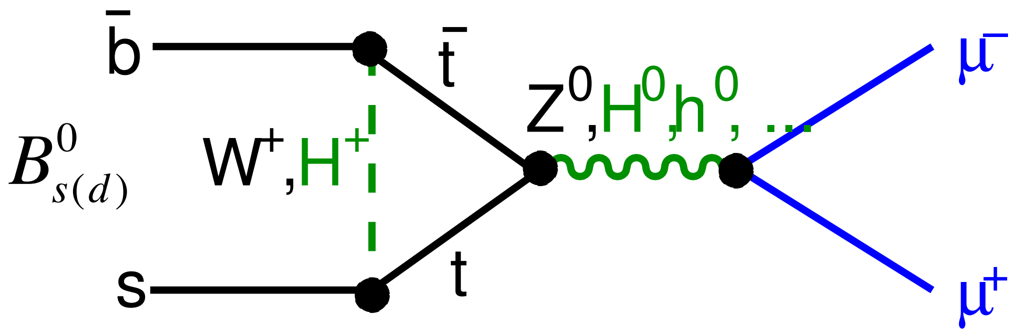
Search for $B^0_{(s)} \rightarrow \mu^+\mu^-$

- The rare flavor changing neutral current decays are highly suppressed in the SM

$$\mathcal{B}(B^0_s \rightarrow \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9}$$
$$\mathcal{B}(B^0 \rightarrow \mu^+\mu^-) = (1.0 \pm 0.1) \times 10^{-10}$$

A. Buras 1012.1447

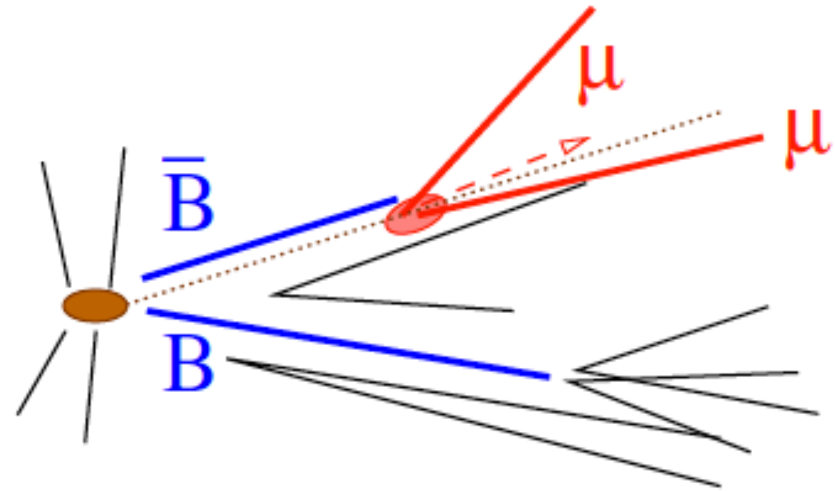


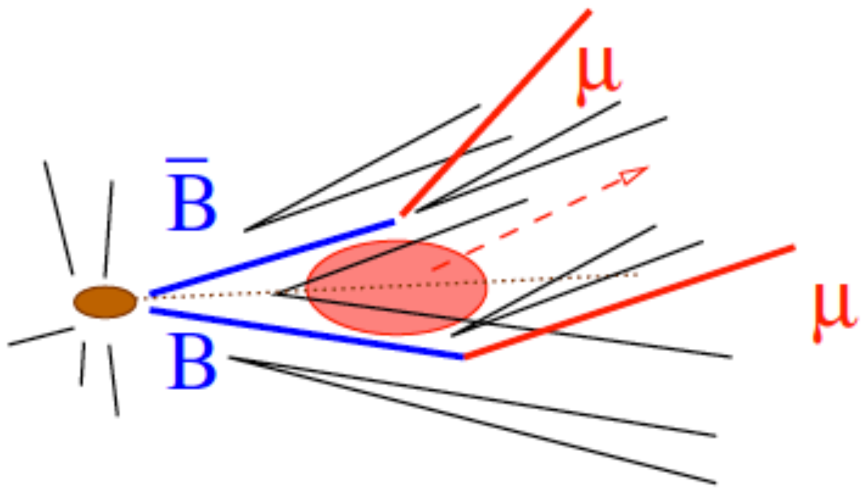


- New physics scenarios can significantly enhance the BR's
  - In MSSM BR $\propto (\tan\beta)^6$
  - Especially sensitive to models with extended Higgs sectors
- Small theoretical uncertainties and high sensitivity to NP make this a Golden Channel

Analysis overview

- Signal
  - Clean B decay with only 2 muons
  - Long-lived B produces well separated vertex
- Background
  - Combinatorial: 2 semi-muonic B decays
  - A semi-muonic B decay plus a misidentified charged hadron
  - Rare single B decays, such as
    - $B_s^0 \to K^- K^+$ (peaking)
    - $B_s^0 \to K^- \mu^+ \nu$ (non-peaking)

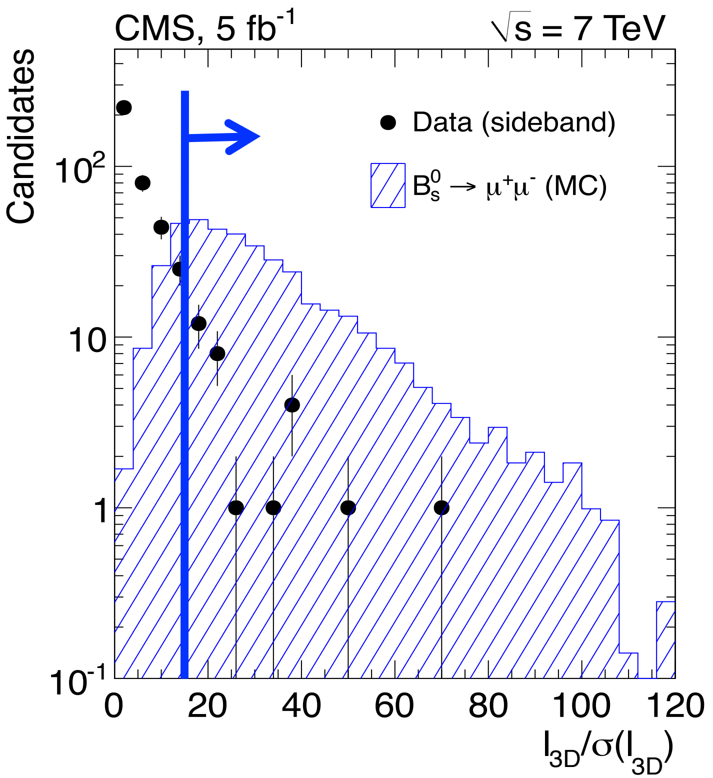


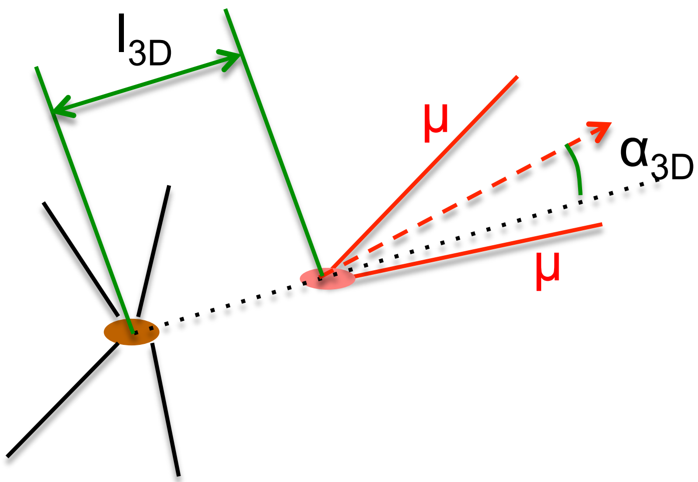


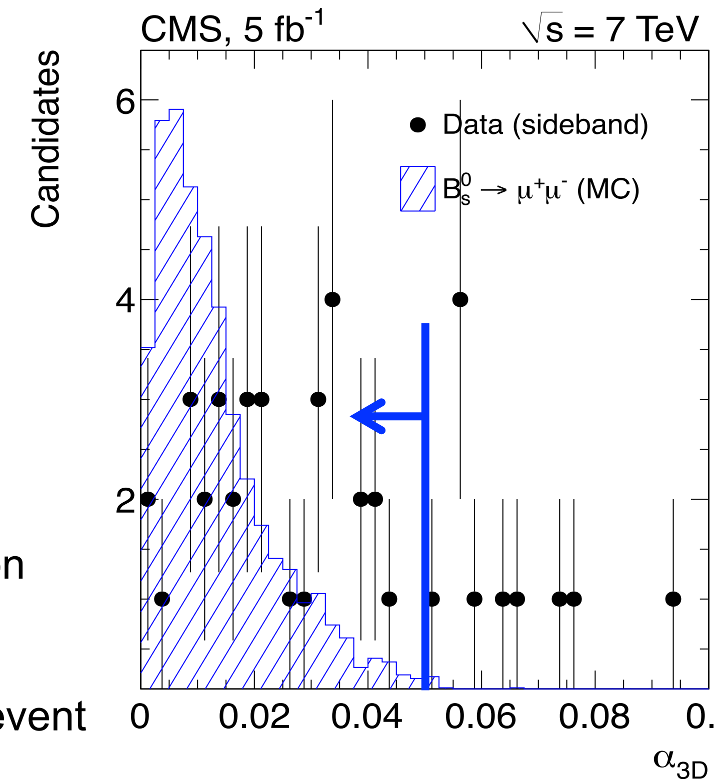
- Main handles: good dimuon vertex; correct B mass; momentum pointing to interaction point

Signal selection

- Mass windows: 5.2-5.3 GeV for B^0 and 5.3-5.45 GeV for B_s^0
  - Mass resolution 36-80 MeV depending on rapidity
- Split into barrel (both $|\eta_\mu| < 1.4$) and endcap channels
- Selection cuts: 3D flight length significance (I_{3D}), momentum points back to primary vertex (α_{3D}), $p_{T\mu} > 4.0$ or 4.5 GeV, $p_{TB} > 6.5$ GeV, good B vertex fit, and isolated decay (next slide)







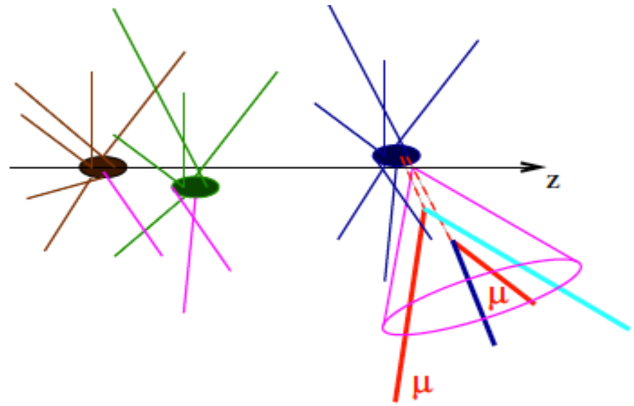
– Select best primary vertex based on consistency with B candidate momentum direction
– Average of 8 primary vertices per event

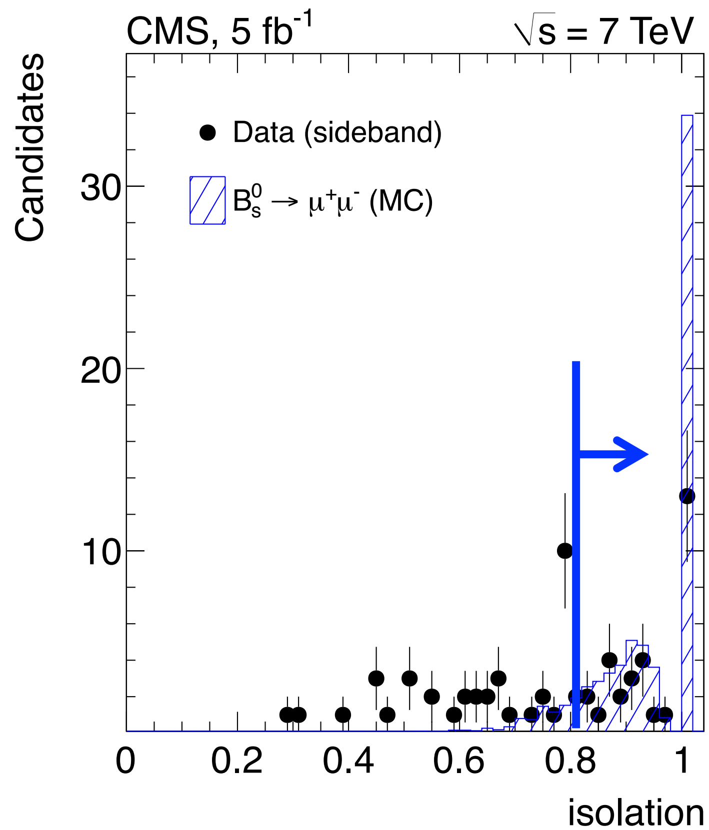
Signal selection: isolation

- Require relative isolation of muon pair

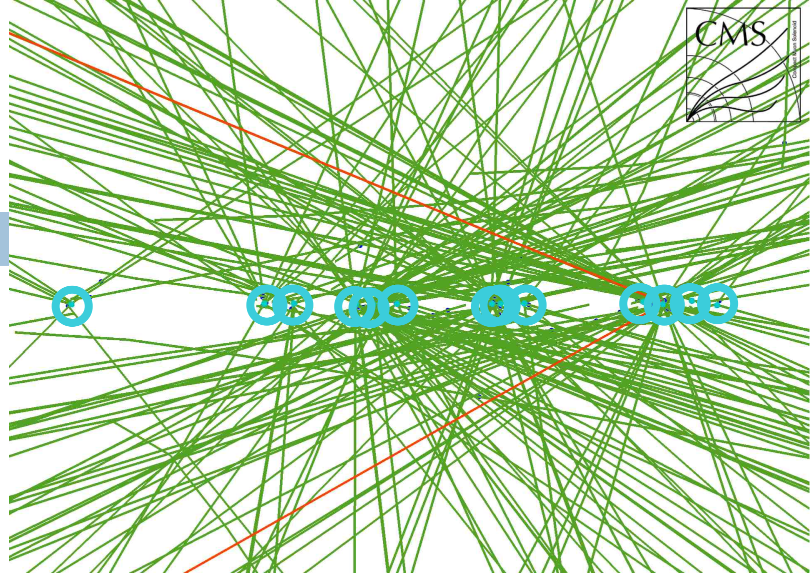
$$I = \frac{p_\perp(\mu^+\mu^-)}{p_\perp(\mu^+\mu^-) + \sum_{\Delta R<0.7} p_\perp}$$

  - Cone of $\Delta R = 0.7$ around the dimuon momentum
  - Include all tracks with $p_T > 900$ MeV from same primary vertex or within 500 μm of B vertex
  - Require isolation > 0.75
- All selection criteria have been optimized for limit sensitivity before unblinding signal region

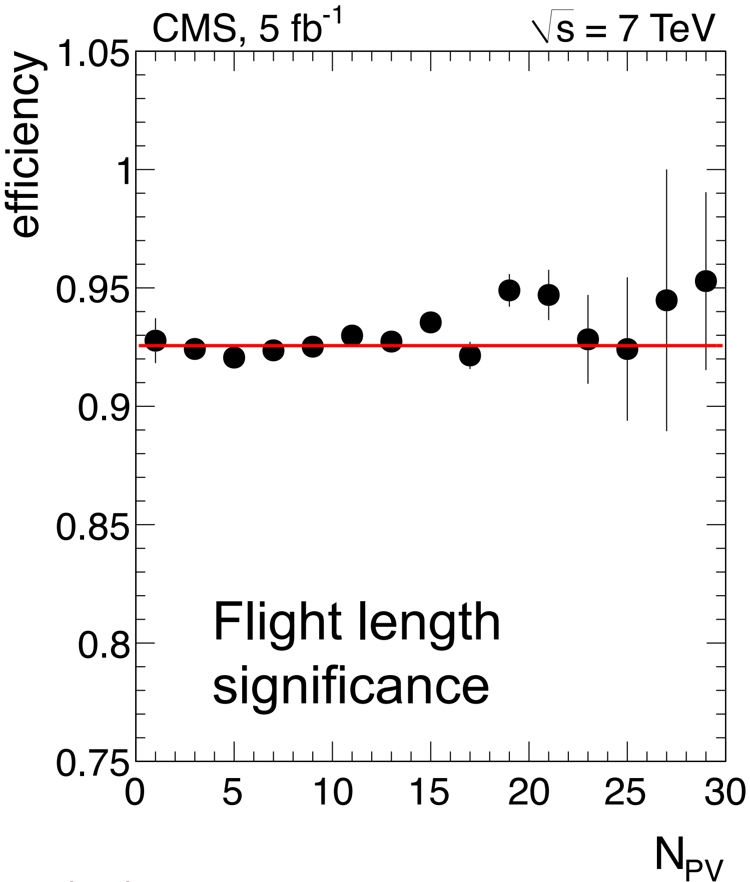


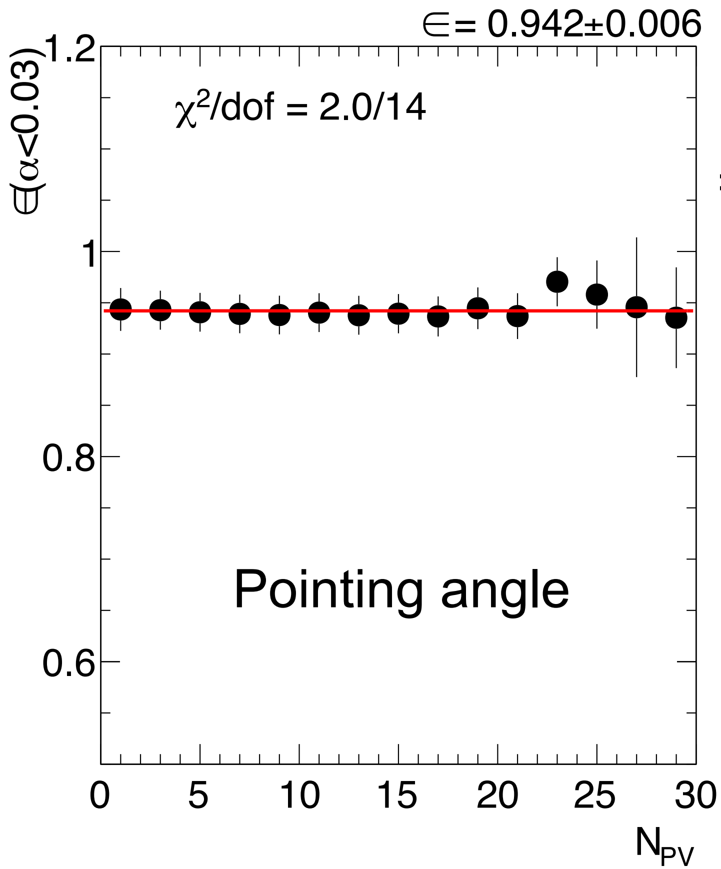


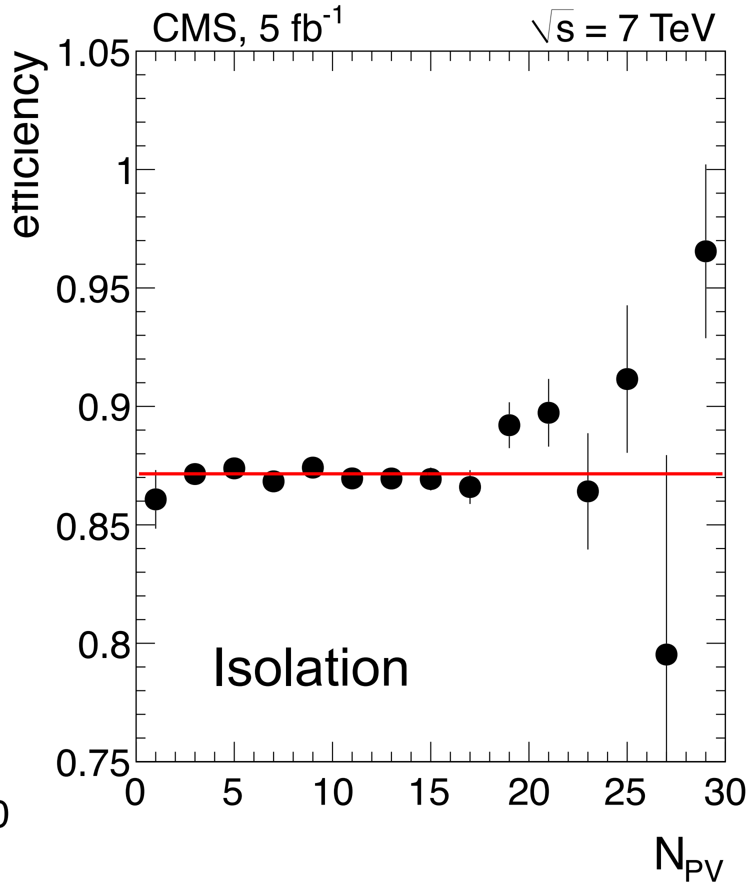
Pileup independence



- Check influence of pileup on selection cuts with $B^+ \rightarrow J/\Psi(\mu^-\mu^+)K^+$ events in data
- Confirm with MC studies
- No significant dependence in efficiency vs pileup out to ~30 PV's

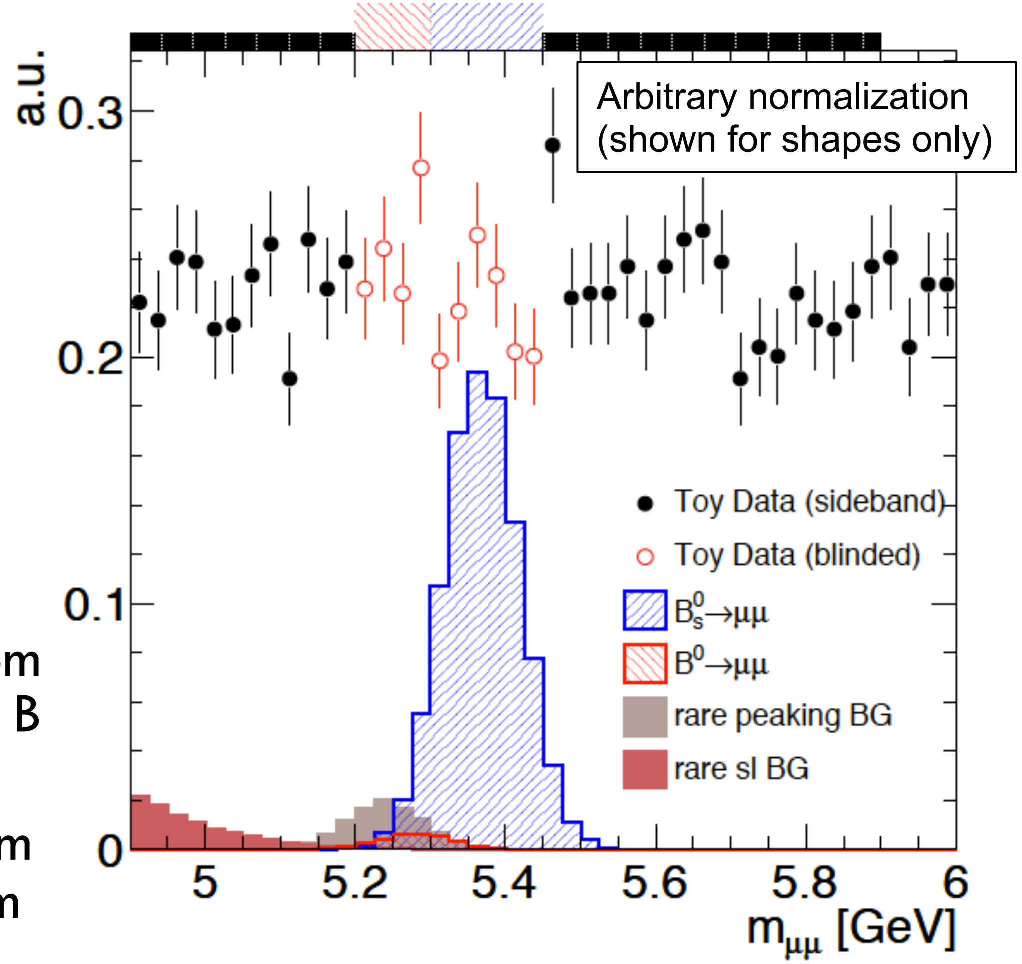






Background estimation

- Non-peaking background measured in data
  - Count events in B mass sidebands 4.80-5.20 GeV and 5.45-6.00 GeV
  - Interpolate to signal region with assumption of flat shape
- Peaking background obtained from MC with inputs from data
  - B→hh backgrounds with two muons from misidentified charged hadrons peak in B mass
  - Measure muon mis-ID rates in data from identified K and π from D(*) and p from Λ samples



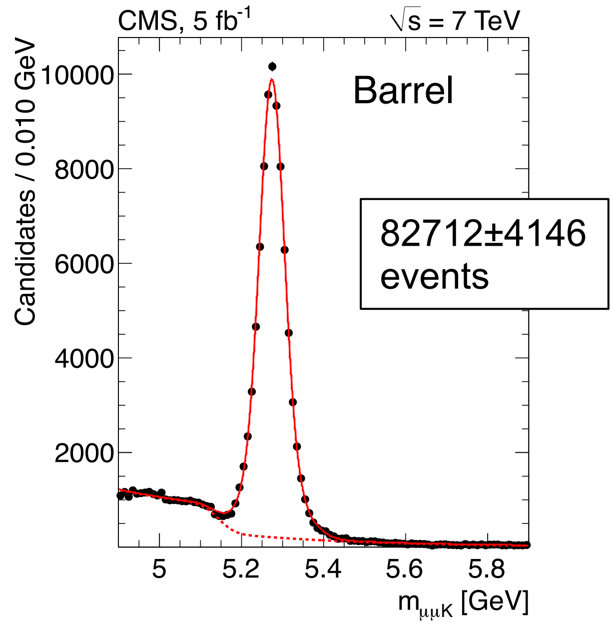
  - Use MC without muon selection cuts to simulate backgrounds and apply fake rate measurements from data
  - Affects B^0 more than B_s^0 because backgrounds peak low

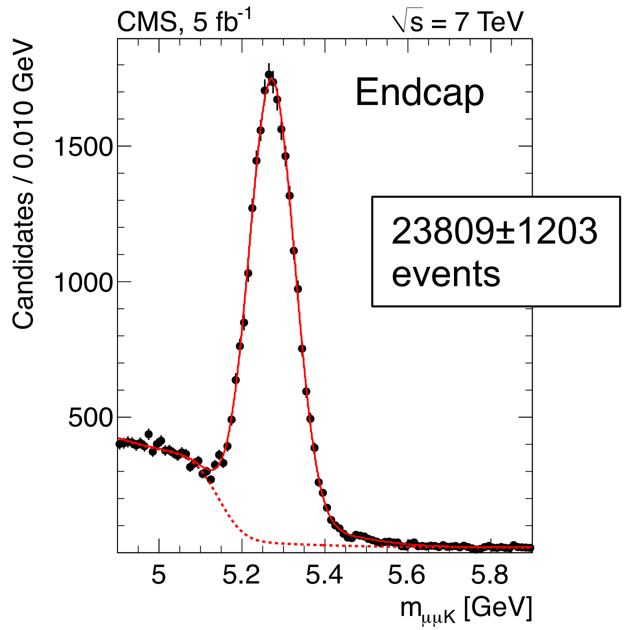
BR calculation: normalized to B^+

- Measure $B_s^0 \to \mu^-\mu^+$ branching fraction relative to normalization channel $B^+ \to J/\Psi(\mu^-\mu^+)K^+$
  - Reduce many systematic effects with similar reconstruction and triggering techniques

$$\boxed{B(B_s^0 \to \mu\mu) = \frac{N(B_s^0 \to \mu\mu)}{N(B^+ \to J/\Psi K)} \times \frac{\varepsilon_{B^+}}{\varepsilon_{B_s}} \times \frac{f_u}{f_s} \times B(B^+ \to J/\Psi K)}$$

- $B(B^+ \to J/\Psi K)$ is well known and relatively large
- Take f_u/f_s from LHCb [arXiv:1111.2357]
- Only need relative efficiency terms
- No need for absolute luminosity measurement
- Similar reconstruction cuts for B^+ as signal, but from tighter trigger



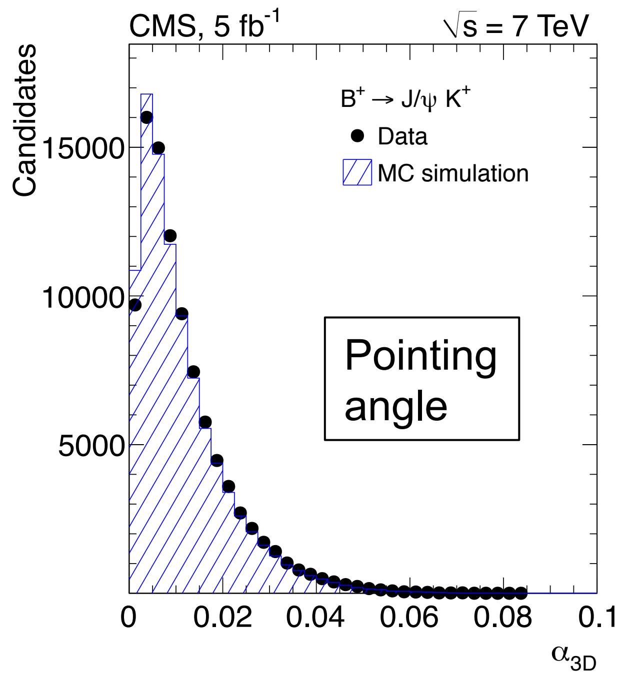


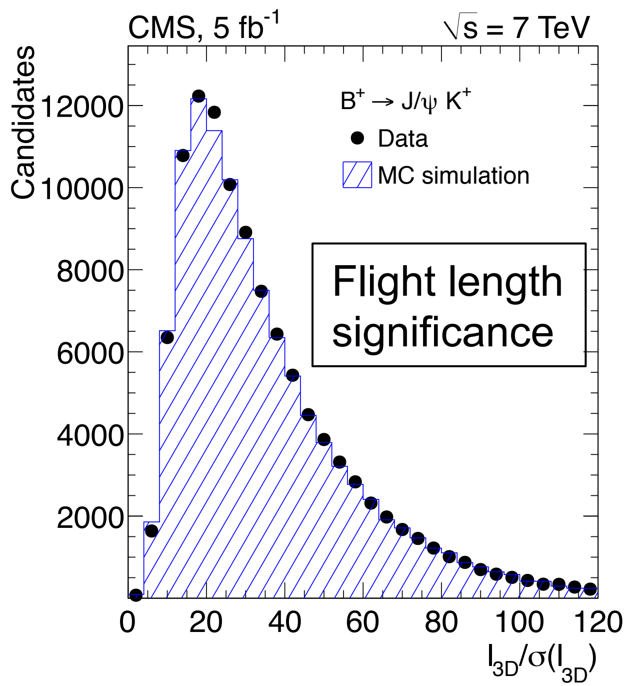
Selection efficiency

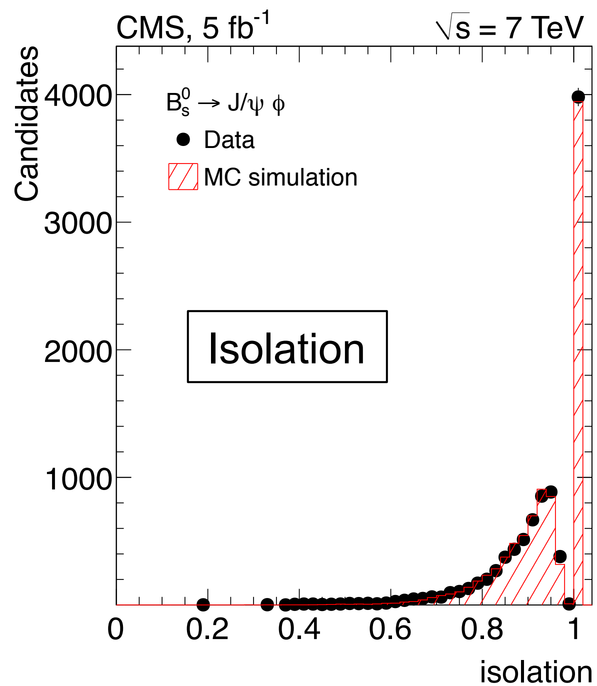
- Signal and normalization efficiencies calculated in MC
  - Overall signal efficiency 0.29% in the barrel and 0.16% in the endcap
  - Overall normalization efficiency 0.11% (0.03%) in the barrel (endcap)
- Validate MC performance with control samples:

$$B_s^0 \to J/\Psi(\mu^-\mu^+)\phi \qquad B^+ \to J/\Psi(\mu^-\mu^+)K^+$$

- Good agreement observed
- Residual differences used as systematics







Trigger efficiency

- Dedicated signal trigger for $B \to \mu^+\mu^-$
  - Opposite charge muons with mass 4.8-6.0 GeV
  - $p_T(\mu) > 4$ GeV, $p_T(\mu\mu) > 4$ (6) GeV in barrel (endcap)
  - Dimuon vertex fit confidence > 0.5%
- Normalization trigger
  - Same displaced dimuon trigger as in $\Lambda_b \to J/\Psi\Lambda$ analysis
- Trigger efficiency measured after selection cuts ≈ 80%
  - Stable with time
  - Measured in MC
  - Cross checked with measurement in data

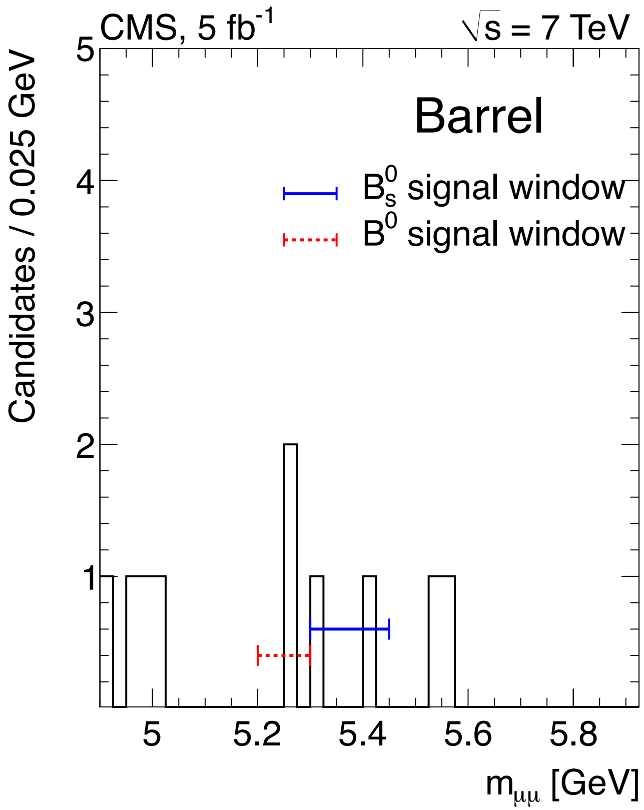
Systematic uncertainties

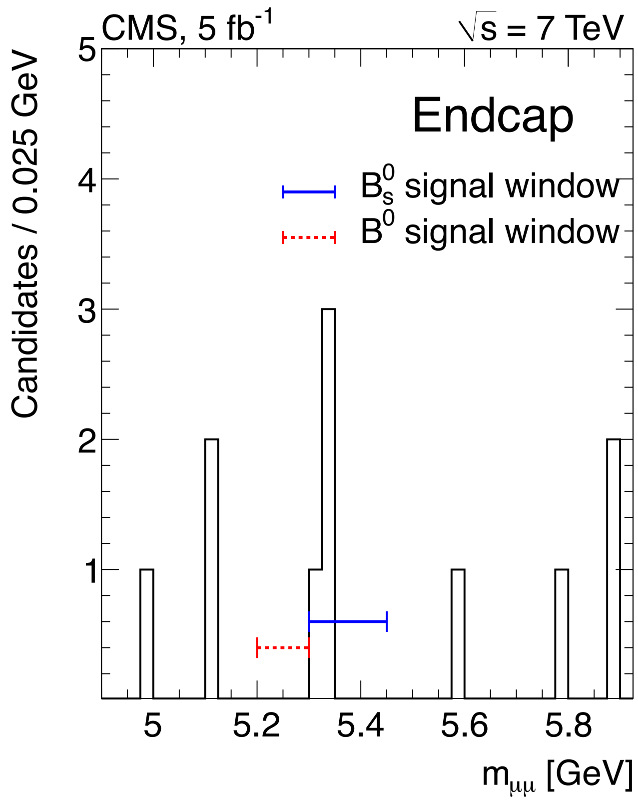
- Fragmentation functions (fs/fu) 8%
- Background
  - Combinatorial: loosened selection cuts; inverted isolation studies 4%
  - Rare peaking decays: BF and mis-ID uncertainties 20%
- Signal
  - Acceptance: variation from different bb production processes 3.5/5%
  - Selection efficiency: comparison of data and MC cut by cut 3%
  - Track momentum scale: from J/ψ resonance reconstructed mass 3%
- Normalization
  - Selection efficiency: comparison of data and MC cut by cut 4%
  - Hadron track efficiency: from data with D^* decay studies 4%
  - Yield fits: variation of fitting functions 4%
- Muon identification and trigger
  - Evaluated from data/MC differences
  - Muon identification efficiency ratio 4/8%
  - Trigger efficiency ratio 3/6%
- Rare decays background
- Total (barrel/endcap) 24/26%

$B^0_{(s)} \rightarrow \mu^+\mu^-$ Results

Variable	$B^0 \to \mu^+\mu^-$ Barrel	$B^0_s \to \mu^+\mu^-$ Barrel	$B^0 \to \mu^+\mu^-$ Endcap	$B^0_s \to \mu^+\mu^-$ Endcap
Signal (SM)	0.24 ± 0.02	2.70 ± 0.41	0.10 ± 0.01	1.23 ± 0.18
Combinatorial bg	0.40 ± 0.34	0.59 ± 0.50	0.76 ± 0.35	1.14 ± 0.53
Peaking bg	0.33 ± 0.07	0.18 ± 0.06	0.15 ± 0.03	0.08 ± 0.02
Sum	0.97 ± 0.35	3.47 ± 0.65	1.01 ± 0.35	2.45 ± 0.56
Observed	2	2	0	4

- Observation consistent with expectation from background + SM signal in all 4 channels



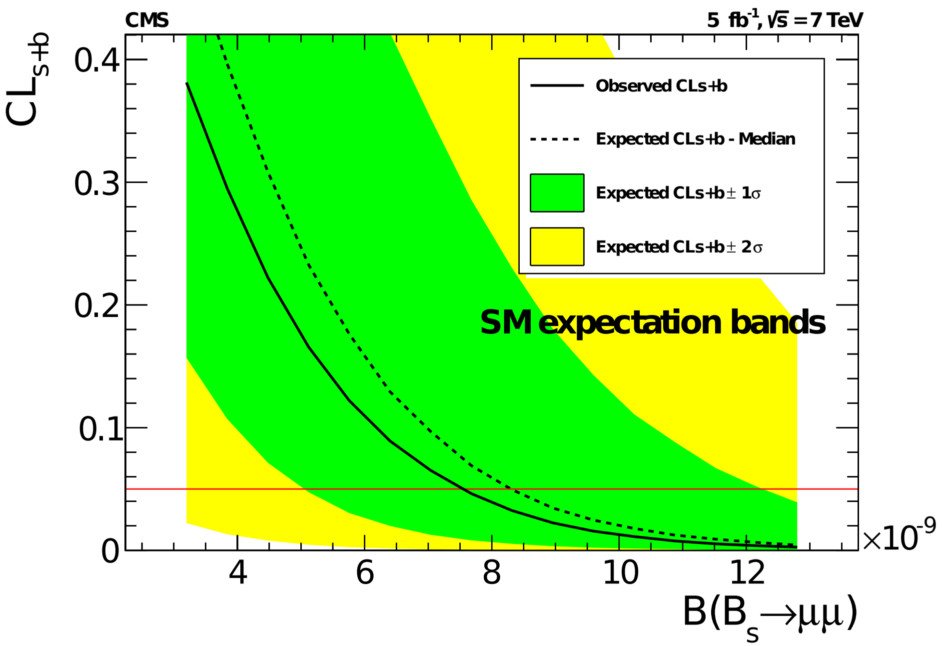


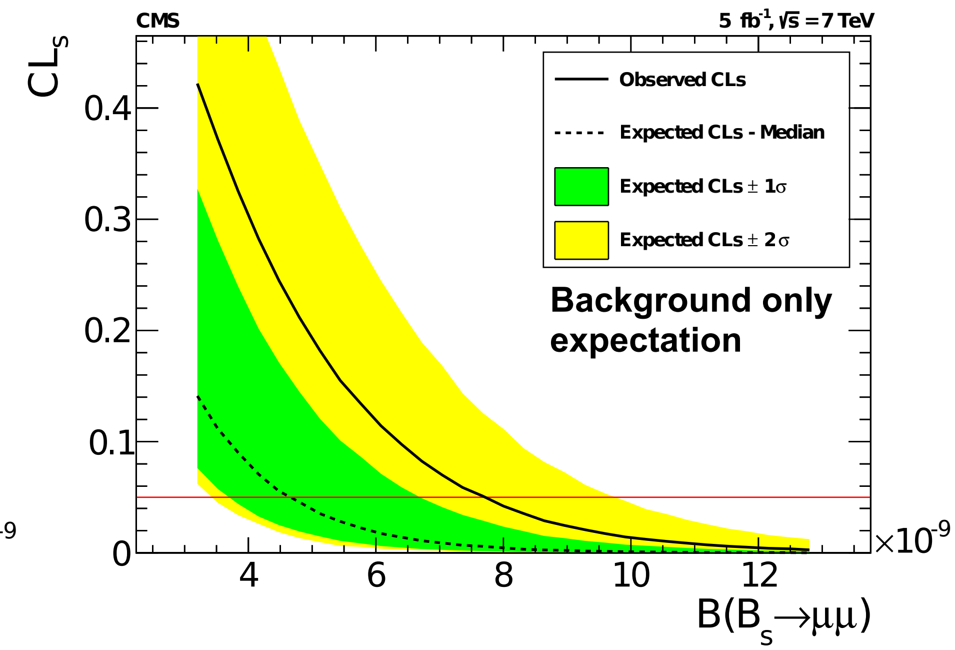
Branching fraction upper limits

- Upper limits for $B_s^0 \to \mu^- \mu^+$ and $B^0 \to \mu^- \mu^+$ computed with CLs
  - Combine barrel and endcap channels
  - Background only p value for $B_s^0 \to \mu^- \mu^+$ = 0.11 (1.2σ)

upper limit (95%CL)	observed	(median) expected
$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	7.7×10^{-9}	8.4×10^{-9}
$\mathcal{B}(B^0 \to \mu^+\mu^-)$	1.8×10^{-9}	1.6×10^{-9}

arXiv:1203.3976
Accepted by JHEP

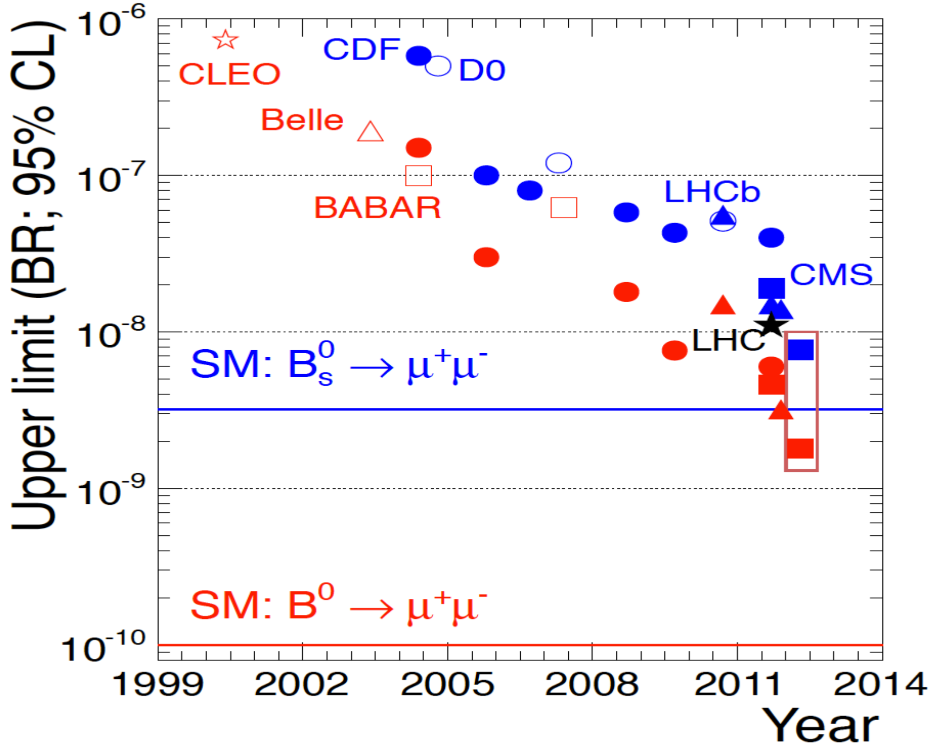




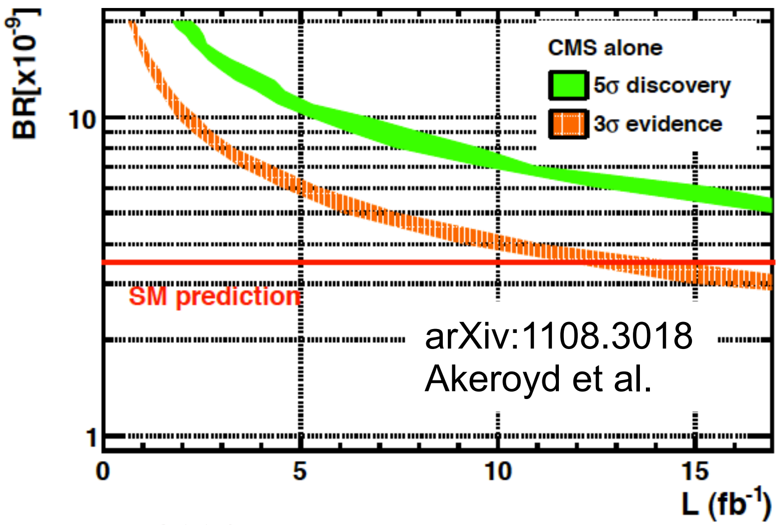
Comparison and prospects

- UL's steadily falling over time
- $B_s^0 \to \mu^- \mu^+$ now ~2× SM

95% UL's (×10⁻⁹)	CMS 5 fb-1	Atlas 2 fb-1	LHCb 1 fb-1	CDF 10 fb-1	D0 6 fb-1
$B_s \to \mu\mu$	7.7	22	4.5	31	51
$B^0 \to \mu\mu$	1.8	---	1.0	4.6	---

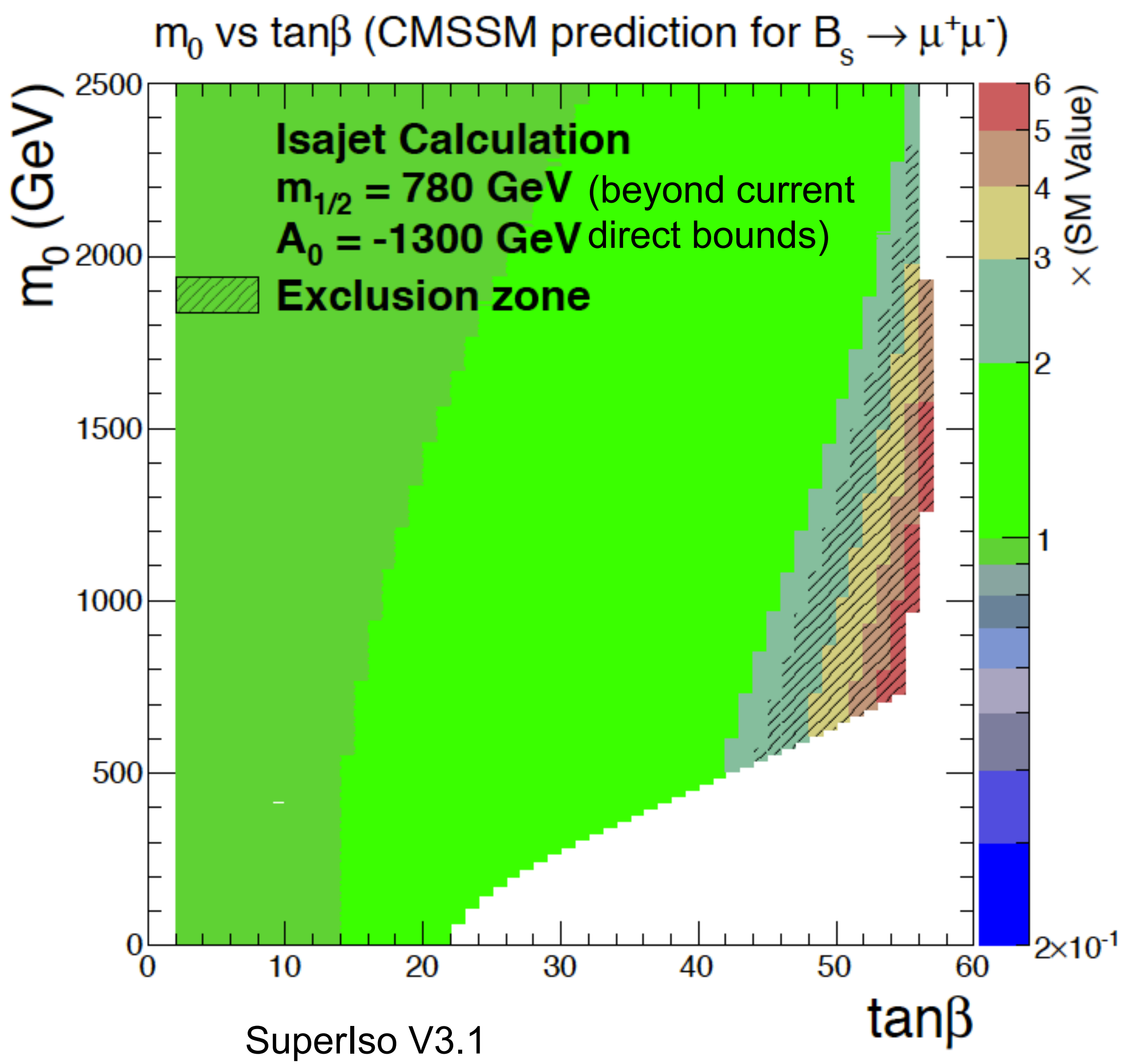


- CDF also reports central value of $13^{+9}_{-7} \times 10^{-9}$ for $B_s^0 \to \mu^- \mu^+$
- LHC already doubled 2011 dataset
- Total ~20 fb^{-1} possible by end of 2012
- 2012 is the year to start to see or rule out SM $B_s^0 \to \mu^- \mu^+$



Prospects and interpretation

- New $B_s \to \mu\mu$ limit constrains CMSSM parameter space beyond direct searches for many scenarios
  - Large tan β gives largest enhancements
- Large swaths of parameter space are within 2012 reach
- New physics can also suppress $B_s \to \mu\mu$, too!



SuperIso V3.1
CPC, 180, 1579

Conclusion

- Very active heavy flavor physics program at CMS is off and running
- Results span wide range of physics interests
  - Perturbative QCD studies in heavy quark production
  - New and exotic state searches and measurements
  - Indirect searches for new physics
- Many more interesting topics accessible with existing and future data
  - $B^0 \to K^{*0}\mu\mu$, $\Lambda_b \to \Lambda\mu\mu$, $B_c \to J/\psi\pi$, CP studies in $B_s^0 \to J/\psi\phi$, A_{sl}^b more new b baryons, lifetime measurements, mass measurements, branching fractions, …

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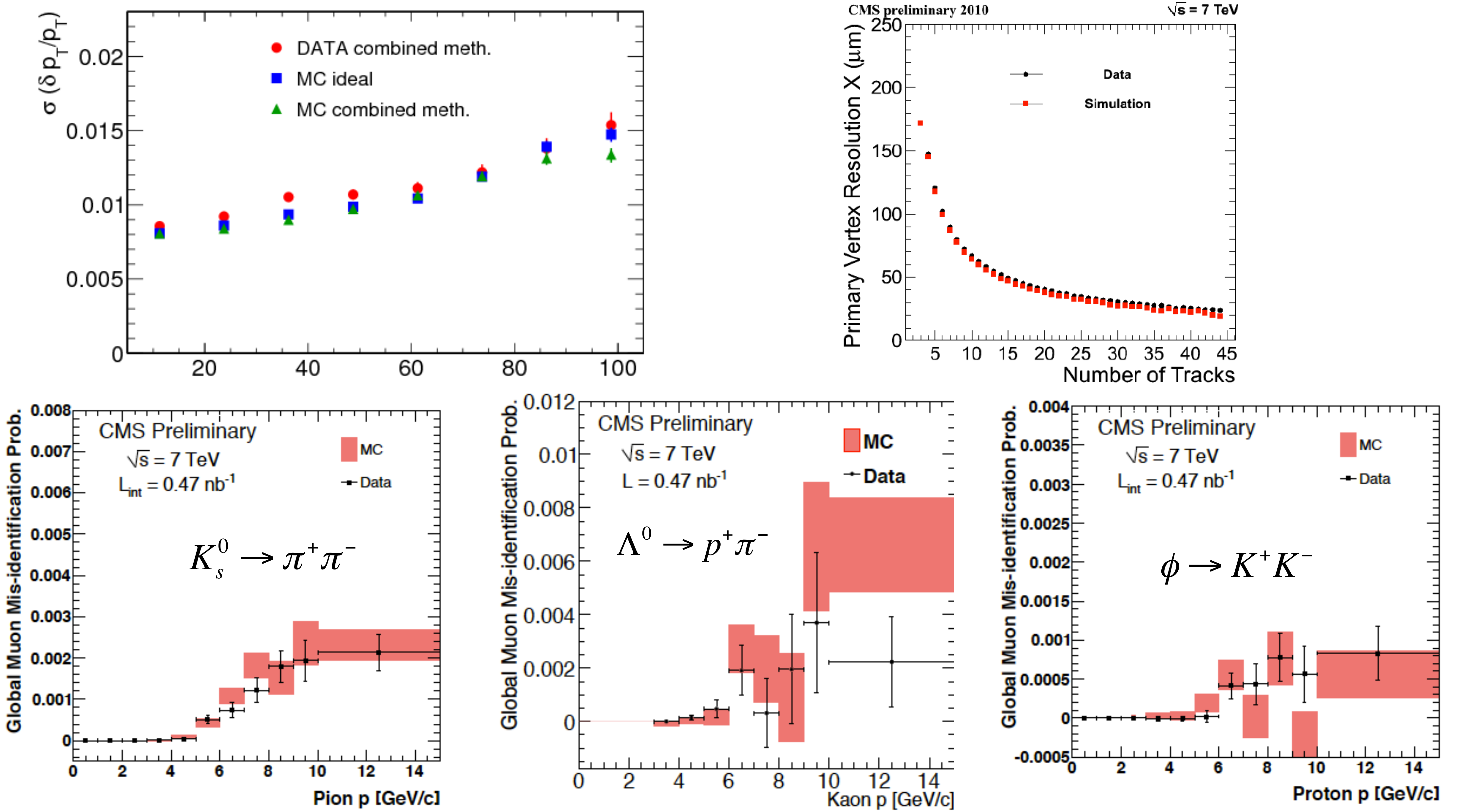
Thank You!

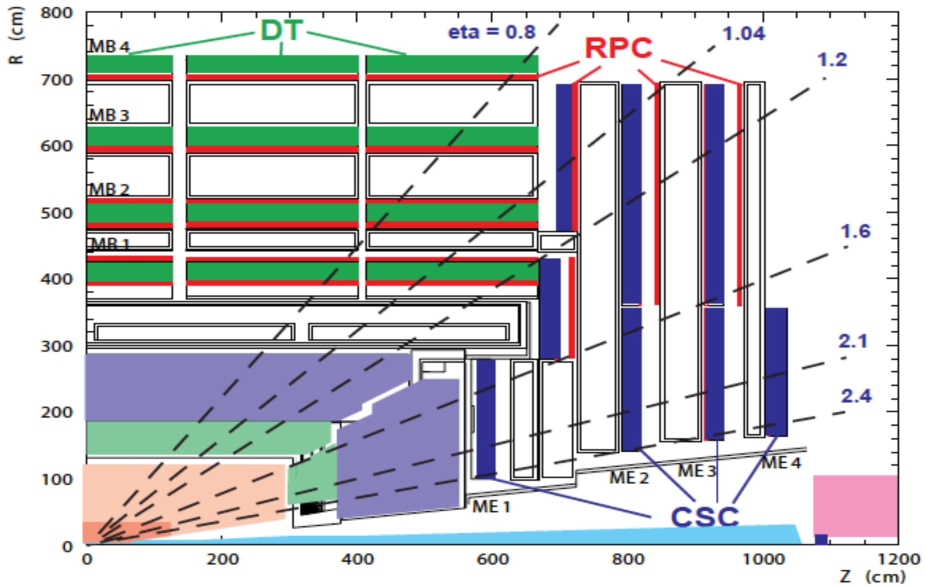
Extra slides

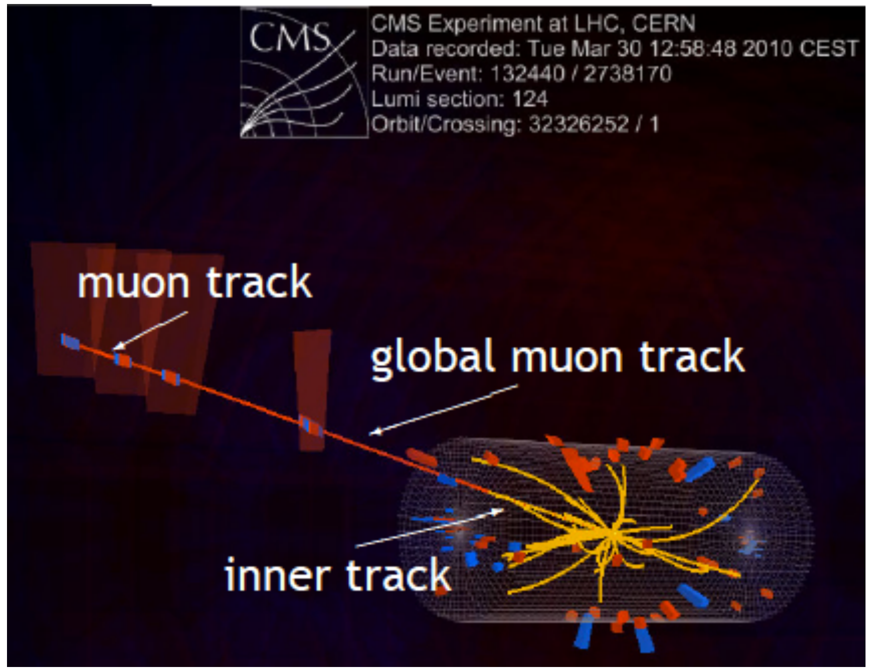
More tracking performance plots



Muon system

- Muons reconstructed with three detector technologies
  - Drift tubes
  - Cathode strip chambers
  - Resistive plate chambers
- Muons required to be found by each of two reconstruction algorithms
  - Outside-in: stand alone track in muon system matched to a compatible track in silicon tracker
  - Inside-out: silicon track matched to compatible hits in muon system
- Low muon mis-ID rates
  - < 0.3% for pions and kaons
  - < 0.05% for protons





Λ_b cross section results

- Λ_b differential cross section results table

$p_T^{\Lambda_b}$ (GeV)	n_{sig} events	ϵ (%)	$d\sigma/dp_T^{\Lambda_b} \times \mathcal{B}(\Lambda_b \to J/\psi\Lambda)$ (pb/GeV)	POWHEG (pb/GeV)	PYTHIA (pb/GeV)
$10-13$	293 ± 22	0.29 ± 0.03	$240 \pm 20 \pm 30$	110^{+40}_{-30}	210
$13-15$	240 ± 18	0.79 ± 0.08	$108 \pm 8 \pm 12$	54^{+21}_{-12}	102
$15-18$	265 ± 19	1.54 ± 0.16	$41 \pm 3 \pm 4$	29^{+10}_{-6}	55
$18-22$	207 ± 16	2.34 ± 0.23	$15.6 \pm 1.2 \pm 1.6$	$13.4^{+4.5}_{-2.7}$	24.0
$22-28$	145 ± 14	3.21 ± 0.34	$5.3 \pm 0.5 \pm 0.6$	$5.3^{+1.6}_{-1.1}$	9.3
$28-50$	87 ± 11	3.96 ± 0.50	$0.70 \pm 0.09 \pm 0.09$	$0.89^{+0.32}_{-0.15}$	1.42
$\lvert y^{\Lambda_b} \rvert$	n_{sig} events	ϵ (%)	$d\sigma/dy^{\Lambda_b} \times \mathcal{B}(\Lambda_b \to J/\psi\Lambda)$ (pb)	POWHEG (pb)	PYTHIA (pb)
$0.0-0.3$	233 ± 17	0.74 ± 0.09	$370 \pm 30 \pm 50$	180^{+70}_{-40}	330
$0.3-0.6$	256 ± 18	0.77 ± 0.09	$390 \pm 30 \pm 50$	170^{+60}_{-40}	330
$0.6-0.9$	206 ± 16	0.81 ± 0.09	$300 \pm 20 \pm 30$	170^{+60}_{-40}	320
$0.9-1.2$	196 ± 17	0.70 ± 0.08	$330 \pm 30 \pm 40$	160^{+60}_{-40}	300
$1.2-1.5$	189 ± 17	0.67 ± 0.09	$330 \pm 30 \pm 50$	150^{+50}_{-40}	280
$1.5-2.0$	162 ± 18	0.65 ± 0.09	$180 \pm 20 \pm 30$	130^{+50}_{-30}	250

$\overline{\Lambda}_b/\Lambda_b$ cross section results

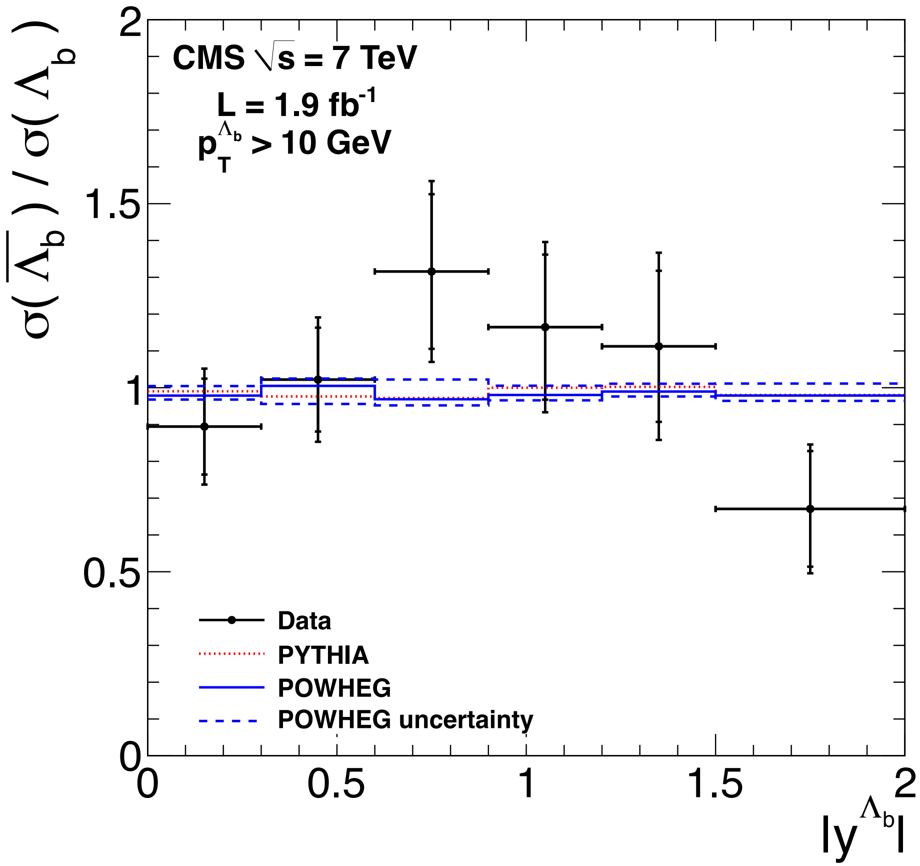
- Λ_b antiparticle/particle ratio results

$p_T^{\Lambda_b}$ (GeV)	Uncorrected $n_{sig}^{\overline{\Lambda}_b}/n_{sig}^{\Lambda_b}$	$\epsilon(\overline{\Lambda}_b)/\epsilon(\Lambda_b)$	Data $\sigma(\overline{\Lambda}_b)/\sigma(\Lambda_b)$	POWHEG $\sigma(\overline{\Lambda}_b)/\sigma(\Lambda_b)$	PYTHIA $\sigma(\overline{\Lambda}_b)/\sigma(\Lambda_b)$
10–13	0.96±0.14	0.84±0.09	1.14±0.17±0.12	$0.98^{+0.02}_{-0.01}$	0.99
13–15	0.76±0.11	0.79±0.09	0.96±0.14±0.10	$0.98^{+0.02}_{-0.01}$	0.98
15–18	0.89±0.13	0.90±0.09	0.98±0.14±0.09	$1.01^{+0.01}_{-0.05}$	0.99
18–22	0.73±0.12	0.95±0.08	0.77±0.12±0.07	$0.97^{+0.05}_{-0.02}$	0.99
22–28	1.26±0.24	0.94±0.10	1.33±0.26±0.14	$0.99^{+0.02}_{-0.03}$	0.99
28–50	0.99±0.25	0.72±0.08	1.37±0.35±0.14	$0.96^{+0.06}_{-0.04}$	0.97

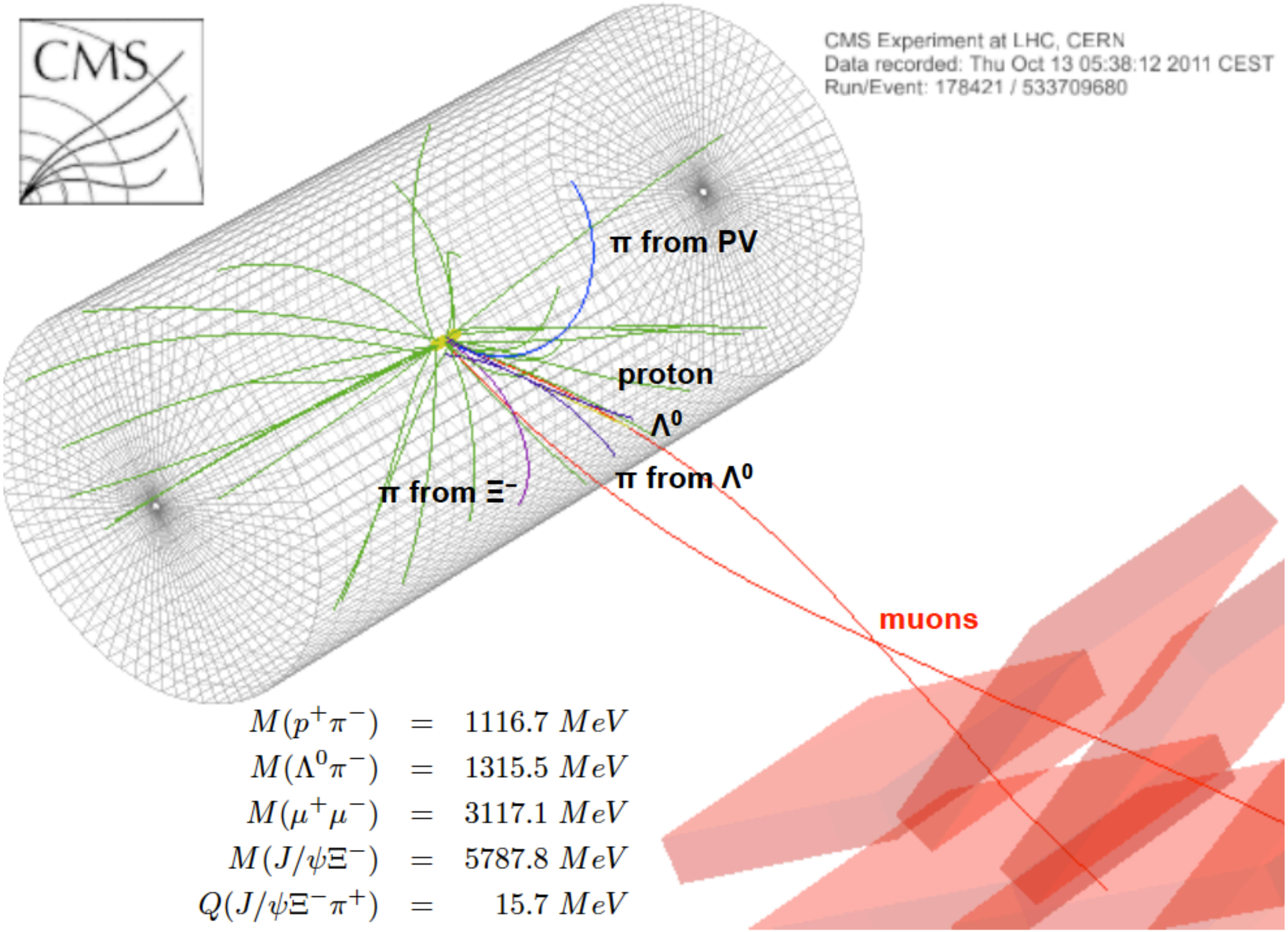
$\lvert y^{\Lambda_b}\rvert$	Uncorrected $n_{sig}^{\overline{\Lambda}_b}/n_{sig}^{\Lambda_b}$	$\epsilon(\overline{\Lambda}_b)/\epsilon(\Lambda_b)$	Data $\sigma(\overline{\Lambda}_b)/\sigma(\Lambda_b)$	POWHEG $\sigma(\overline{\Lambda}_b)/\sigma(\Lambda_b)$	PYTHIA $\sigma(\overline{\Lambda}_b)/\sigma(\Lambda_b)$
0.0–0.3	0.71±0.10	0.79±0.08	0.89±0.13±0.09	$0.98^{+0.02}_{-0.01}$	0.99
0.3–0.6	0.92±0.13	0.90±0.08	1.02±0.14±0.09	$1.01^{+0.01}_{-0.05}$	0.98
0.6–0.9	1.16±0.18	0.88±0.09	1.32±0.21±0.13	$0.97^{+0.05}_{-0.02}$	0.97
0.9–1.2	0.99±0.17	0.85±0.09	1.16±0.20±0.12	$0.98^{+0.03}_{-0.02}$	1.00
1.2–1.5	0.92±0.17	0.82±0.11	1.11±0.20±0.15	$0.99^{+0.02}_{-0.01}$	1.00
1.5–2.0	0.66±0.16	0.99±0.11	0.67±0.16±0.08	$0.98^{+0.03}_{-0.02}$	0.98

$\overline{\Lambda}_b / \Lambda_b$ interpretation

- J. Rosner 1205.1529 suggests non-factorizable effects could lead to the $t\bar{t}$ asymmetry observed at the Tevatron
- Also suggests that the same effects would lead to more Λ_b than anti-Λ_b close to the beamline at the LHC
- Our result is not inconsistent with that, but also not inconsistent with no asymmetry either



Ξ^{*}_{b} candidate event display



$$
\begin{aligned}
M(p^{+}\pi^{-}) &= 1116.7\ MeV \\
M(\Lambda^{0}\pi^{-}) &= 1315.5\ MeV \\
M(\mu^{+}\mu^{-}) &= 3117.1\ MeV \\
M(J/\psi\Xi^{-}) &= 5787.8\ MeV \\
Q(J/\psi\Xi^{-}\pi^{+}) &= 15.7\ MeV
\end{aligned}
$$

Ξ^*_b event selection algorithm

- Ξ_b^- selection algorithm:
  - At every iteration:
    - Choose randomly 2 variables.
    - Randomly: tighten one, loosen the other.
    - Look at Ξ_b^- mass distribution:
      - Signal region: $5.75 < M < 5.83$ GeV
      - Side-bands: $5.69 < M < 5.75$ or $5.83 < M < 5.89$ GeV
    - Calculate: $B = 2N_{side\text{-}bands}/3$; $S = N_{signal} - B$
  - Accept iteration if S does not decrease and:
    - S/sqrt(S+B) increases (then save the iteration) or
    - S/sqrt(S+B) decreases by at most r*10% (r = uniform random number). In this case proceed but do not save the iteration.

Ξ^{*}_{b} event selection

- A sampling of some cut values determined from the algorithm
  - After trigger and Λ reconstruction

$$p_T(p) > 1.0\,\text{GeV},\ p_T(\pi_{\Xi}) > 0.18\,\text{GeV},\ p_T(\Xi^-) > 1.3\,\text{GeV},$$

$$p_T(\Xi_b^-) > 9.8 \text{ or } 10.6\,\text{GeV depending on whether } |\eta(\Xi_b^-)| < 1.2 \text{ or not},$$

$$|\eta(J/\psi)| < 2.15,\ D_{ip}/\sigma_{Dip}(p) > 1.0,\ D_{ip}/\sigma_{Dip}(\pi_{\Lambda}) > 0.66,$$

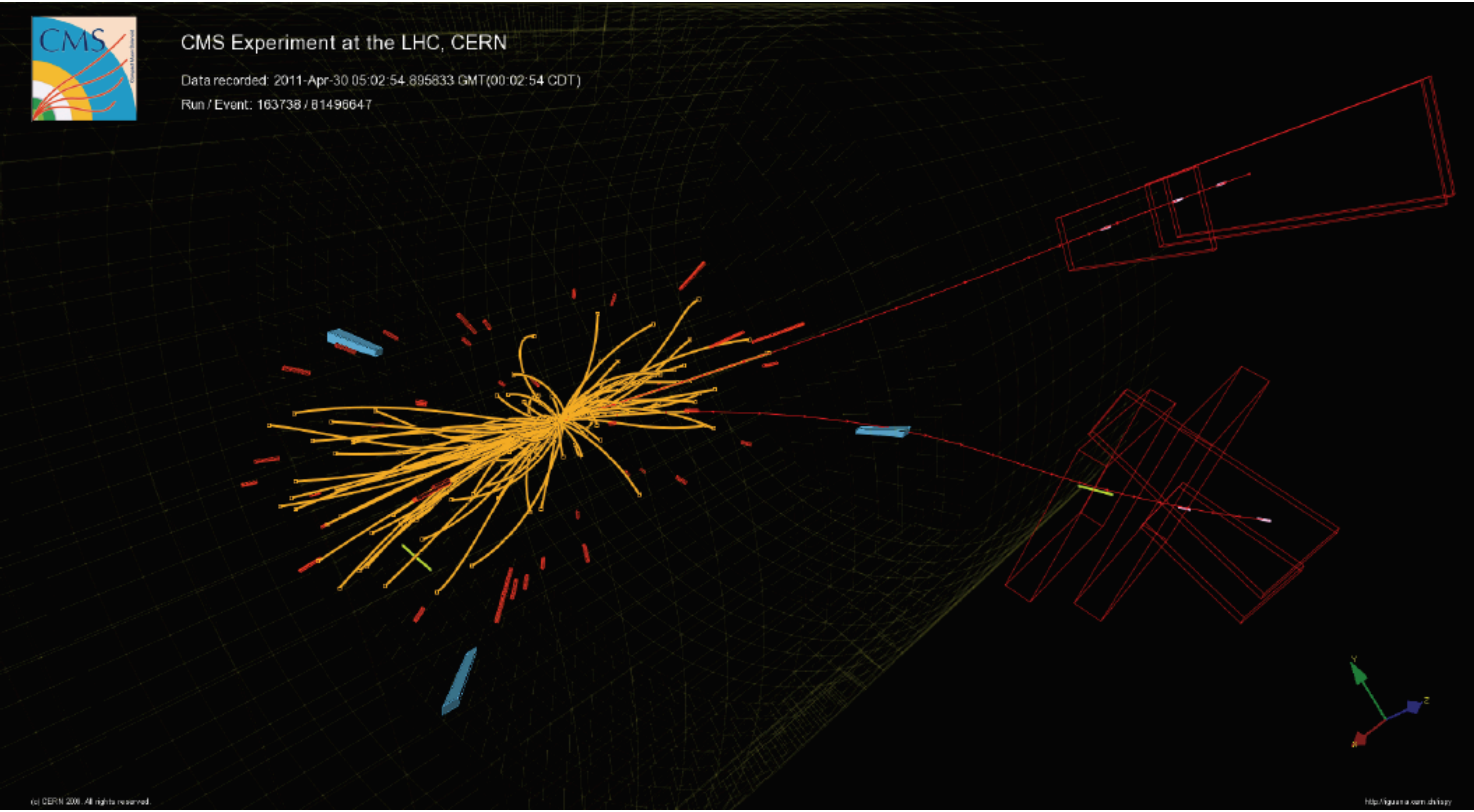
$$L_{xy}/\sigma_{Lxy}(\Xi^-) > 2.8,\ \text{CL}(\Lambda^0) > 2.5\%,\ \text{CL}(\Xi_b^-) > 0.72\%,$$

$$D_{3d}/\sigma_{D3d}(\Xi^- - J/\psi) < 3.1 \quad D_{3d}/\sigma_{D3d}(\Xi_b^- - PV) < 3.5$$

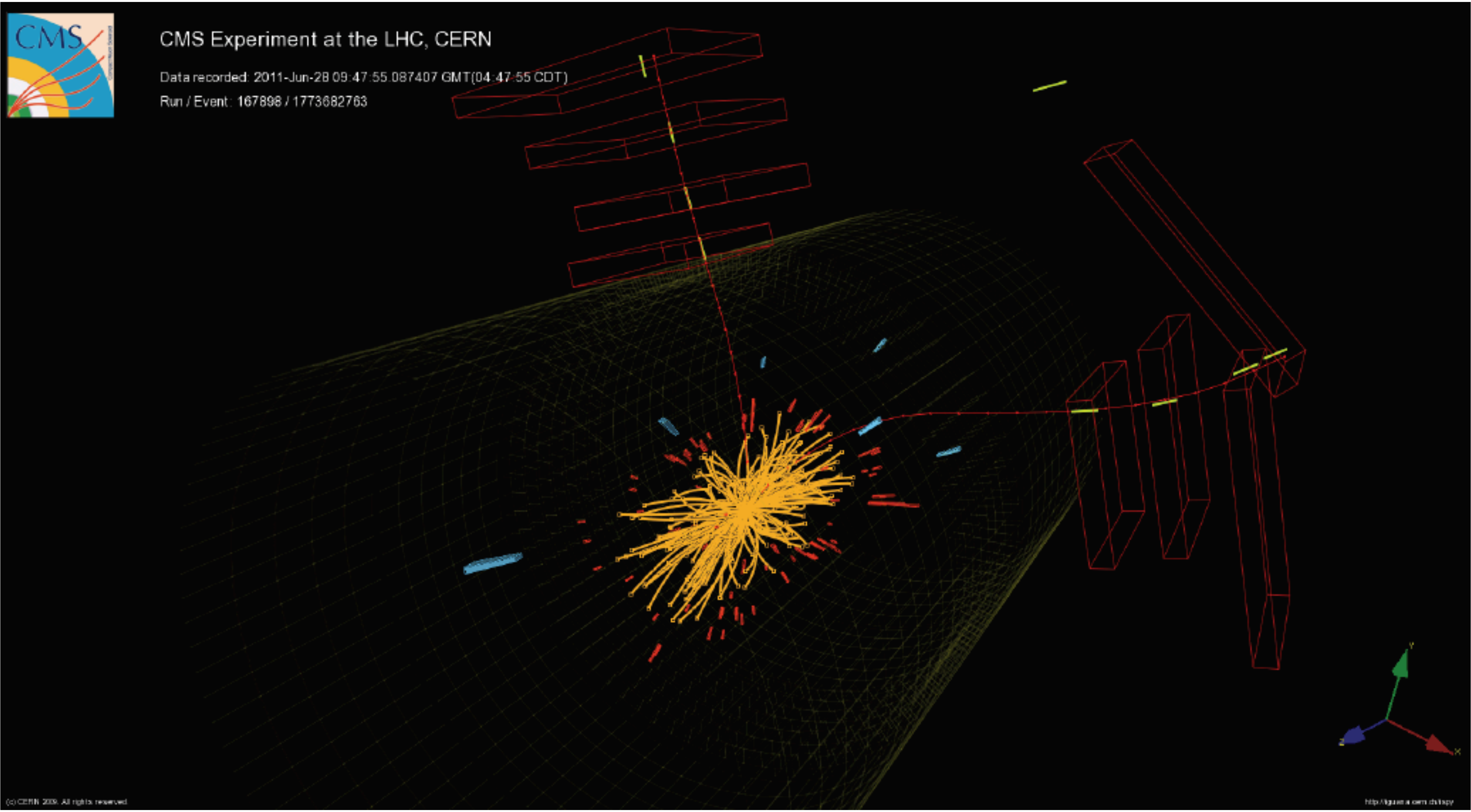
Ξ^*_b systematic effects

- Alternative functional forms for shapes of $p(\Xi_b)$, $p(\pi)$ and angle between Ξ_b and π for toy background shape determination
- Alternative background fit functions
  - Even 0th order polynomial shows significance $> 5\sigma$
- Fit procedure performance on MC compared to MC truth

$B^0_{(s)} \rightarrow \mu^+\mu^-$ Candidate event



$B^0_{(s)} \rightarrow \mu^+\mu^-$ Candidate event

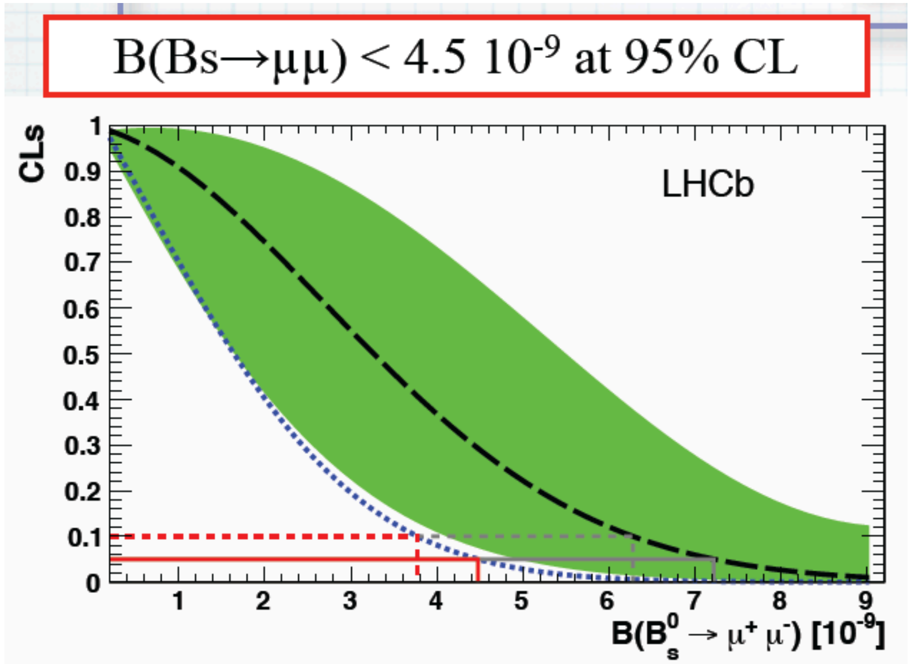


All $B^0_{(s)} \to \mu^+\mu^-$ selection cuts

Variable	Barrel	Endcap	units	comparison to old analysis
$p_{\perp\mu,1} >$	4.5	4.5	GeV	same
$p_{\perp\mu,2} >$ $p_{\perp B} >$ $\ell_{3d} <$	4.0 6.5 1.5	4.2 8.5 1.5	GeV GeV cm	tighter in endcap tighter in endcap tighter
$\alpha <$ $\chi^2/dof <$ $\ell_{3d}/\sigma(\ell_{3d}) >$	0.050 2.2 13.0	0.030 1.8 15.0	rad	looser looser looser
$I >$ $d^0_{ca} >$	0.80 0.015	0.80 0.015	 cm	redefined redefined
$\delta_{3D} <$ $\delta_{3D}/\sigma(\delta_{3D}) <$ $N_{trk} <$	0.008 2.000 2	0.008 2.000 2	cm tracks	new new new

$B_s \rightarrow \mu^+\mu^-$ comparison with LHCb

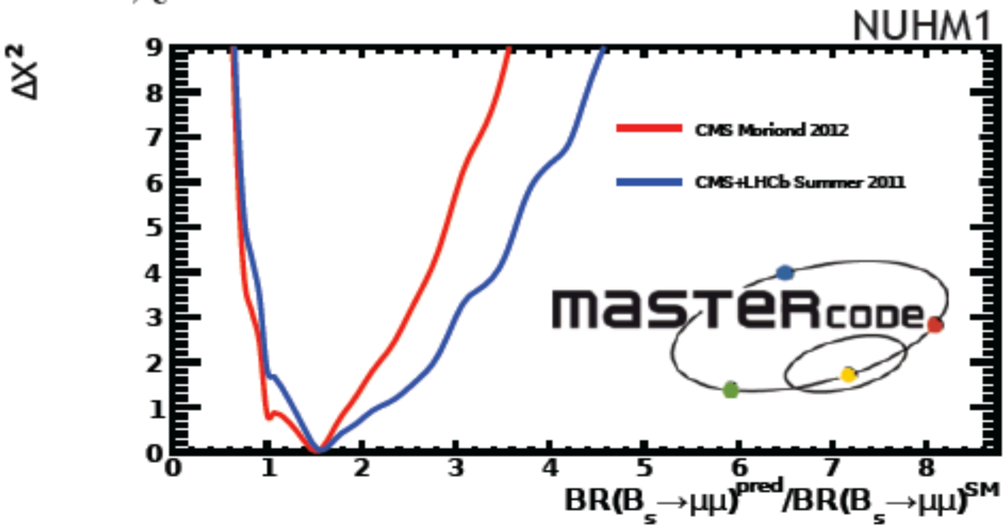
Full 2011 datasets 95% UL's	CMS ($\times 10^{-9}$)	LHCb ($\times 10^{-9}$)
$Bs \rightarrow \mu\mu$ expected	8.8	7.2
$Bs \rightarrow \mu\mu$ observed	7.7	4.5
$B^0 \rightarrow \mu\mu$ expected	1.6	1.1
$B^0 \rightarrow \mu\mu$ observed	1.8	1.0

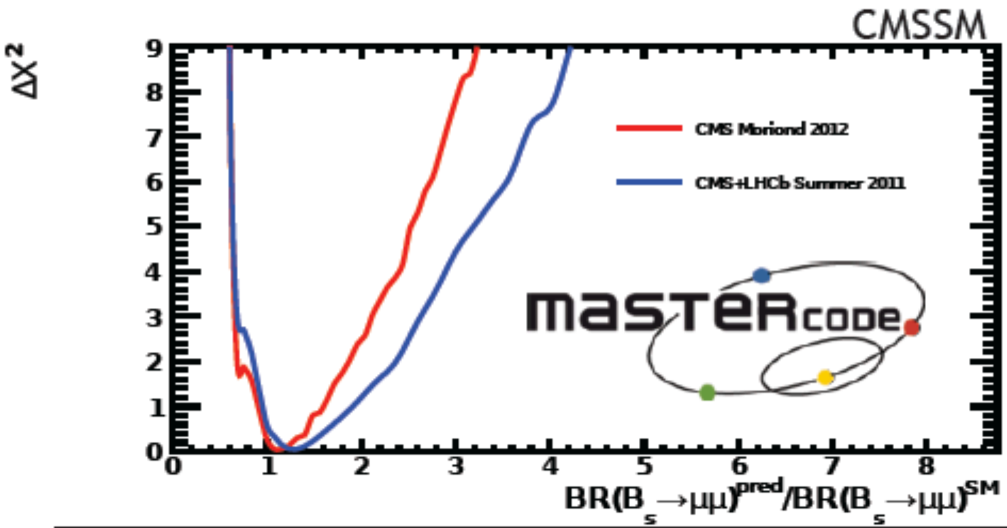


- LHCb advantages
  - Better mass resolution: ~25 MeV vs ~35-70 MeV
  - Higher trigger efficiency
  - More sophisticated analysis: BDT selection, combine different S/B bins vs cut and count in 2 bins
- CMS advantages
  - Higher luminosity: Factor of ~5 in 2011, currently factor of >10 in 2012
  - (More room for improvement in analysis technique)

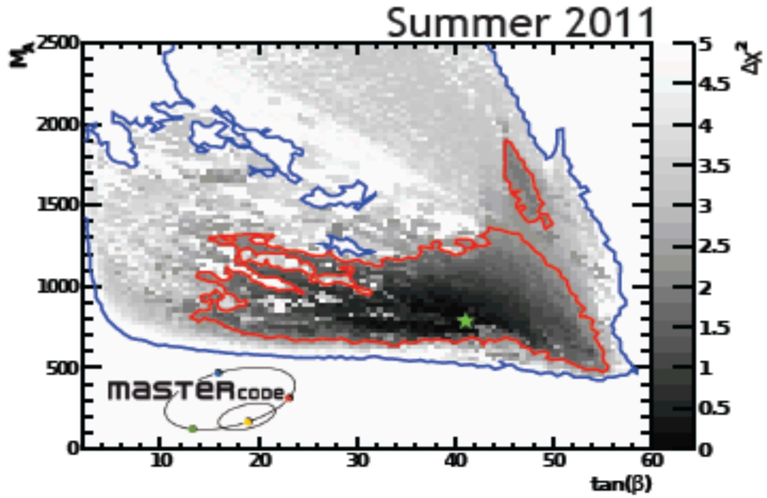
More $B^0_{(s)} \to \mu^+\mu^-$ interpretation

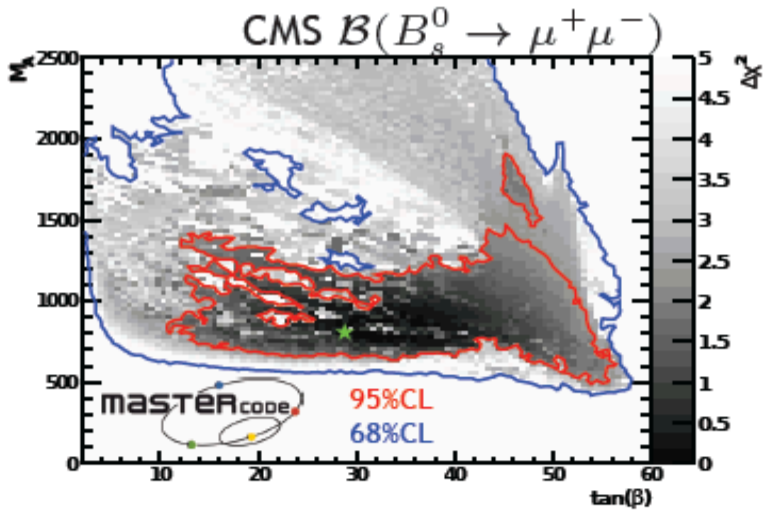
- χ^2 difference





- 'best' fit for CMSSM





MasterCode collaboration arXiv:1112.3564

Combination with LHCb (Summer 2011)

- The two LHC results for $B_s^0 \to \mu^- \mu^+$ have been combined to produce an upper limit of 1.1×10^{-8} at 95% confidence
- All uncertainties treated as uncorrelated, except for f_s/f_d, which is taken to be 100% correlated between the measurements
- Same CL_s upper limit procedure as used for CMS and LHCb results independently
- Background-only p value = 8%, background plus SM signal p value = 55%, CDF central value p value = 0.3%
- Public as CMS PAS BPH-11-019